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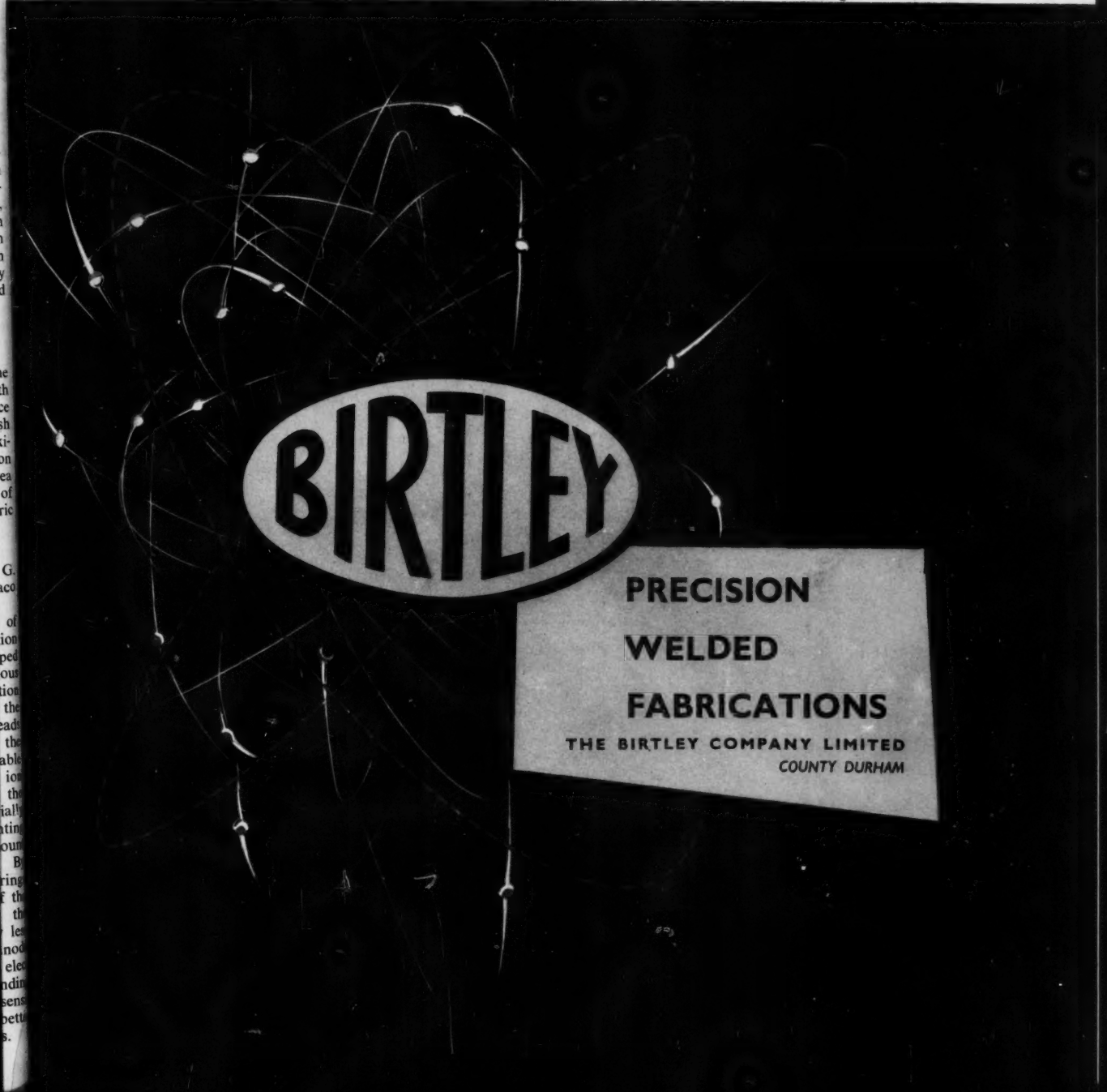

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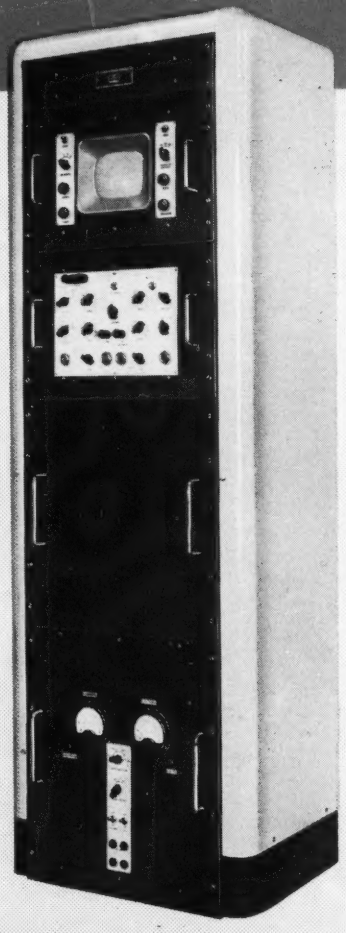

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NUCLEAR ENGINEERING VOL. 1 NO. 3 JUNE, 1956

EDITORIALS

International Collaboration

PEACEFUL developments in atomic energy are providing a continuous meeting ground for nations all over the world to get together to discuss methods of co-operation and to draw up charters of agreement for international understanding and co-operation.

The two main conferences which have recently been held are concerned with the formation of a European federation and an international agency for the distribution of fissile material.

It is by no means clear how either of these two systems will come into being and whether the controls and exchanges discussed will ever be made to function. As a result of the meetings in April of the 12 nations composed of the United Kingdom, the United States, the U.S.S.R., Australia, Belgium, Brazil, Canada, Czechoslovakia, France, India, Portugal and South Africa which comprise the main fissile and fertile material producing countries, a charter was agreed which will be debated by a full assembly of 90 nations, meeting in New York in September. The proposals are that an agency should provide a central organization for the reception of fissile and fertile material from the producing countries for distribution to the underdeveloped nations for the peaceful application of atomic energy. The agency is to be empowered with the right of inspection to ensure that the fissile material supplied will not be diverted to military purposes.

The adoption of this charter is far from settled and it is expected that the meeting in September will be both lengthy and lively. It is quite possible that amendments introduced at this stage will so emasculate the scheme that its effectiveness will be negligible. Even if the charter in its present form is adopted it can only represent a first stage in the setting up of an international control of atomic energy.

Although it is possible that the proposed inspection would vitiate any attempt by a small trigger-happy country to make nuclear war on its neighbour and so precipitate a world conflict, it will do little to prevent the larger powers stock-piling nuclear weapons and beginning a third world war if they feel so inclined. At the same time it is difficult to understand how the scheme will assist the underdeveloped countries more than could be achieved by the establishment of bilateral agreements with one of the major producers or, alternatively, by the formation of a central buying and selling organization without supervisory powers in the countries supplied. There is evidence to suggest that a purely commercial enterprise of this nature is more likely to succeed than a political agreement, which—history has shown—member nations are only too ready to repudiate as soon as they feel that their ends would be better served by opting out.

Because of its commercial implications there would, therefore, seem a better chance for Euratom to be finally agreed and to operate successfully. A precedent has been established with the European Coal and Steel Community which has co-ordinated the European coal and steel production with notable success for some years. In the recent six-nation conference attended by Holland, Western Germany, France, Belgium, Italy and Luxembourg, the vital issue of control over military developments in atomic energy was side-stepped and although some discussion at the foreign ministers' conference on May 29 is to have been expected it is unlikely that any real agreement can be reached which does not permit member nations to proceed with their own military programmes under whatever pressure they think fit. It has been suggested that the terms of the six-nation recommendations are too broad for the countries to be able to carry out the proposed plans, concerned as they are with matters other than atomic energy. The free integrated technical effort of Europe would be impressive both in scale and quality but there is a strong possibility that political interests will severely limit its operational effectiveness for many years to come.

In the forefront of the plans for atomic energy co-operation is the building of a diffusion plant, a project which would severely strain the resources of any one nation, but the allocation of the initial products of this plant when demand for fissile material will be at its highest is liable to raise considerable complications. The responsibility would lie with the European agency which presumably would be set up on lines not unlike those proposed by the 12 nations conference for the world. The question then arises what relation the European agency would have to the international agency and whether member countries of Euratom would deal with the international agency individually or only through the European agency. This is particularly complicated by the fact that Euratom will be composed partly of suppliers of fissile material and partly of prospective buyers and that the mixed role, therefore, of this federation in the world organization will be difficult to establish.

To a lesser extent this also applies to the customs union in which it is expected that the United Kingdom will maintain a position not unlike that held in the European Coal and Steel Community but grave doubts have been expressed whether agreements can ever be reached on the question of tariffs even for atomic energy products alone, particularly as with power station equipment for example the border line between goods specifically devoted to atomic energy and those subject to normal regulations will be hard to define. The two co-operative bodies discussed are by no means the only international tie-ups that have

been agreed or are pending. O.E.E.C. which recently commissioned a detailed study of fuel and power requirements must somehow be linked in with Euratom and U.N.O. undertakings.

Outside Europe also there has been a general rush to create economic and political grounds for mutual assistance. A number of bilateral agreements have already been signed and facilities for the exchange of atomic energy information and goods is already in hand for example between India and Canada under the Colombo Plan. France has been urging that there should be an international investigation of other forms of power generation such as solar energy and very shortly the exchange of information and possibly materials connected with thermo-nuclear utilization will become an issue.

The optimum path for the United Kingdom to follow is thus anything but clear and we must content ourselves with watching developments as they arise and at the same time being prepared to enter into any international co-operative scheme that has a sound basis for mutual exchange and understanding.

Whilst a large measure of independence of action from the commercial and military standpoints must be maintained a studied policy of isolation can be dangerous.

"Nuclear Engineering" Scholarship

Nuclear Engineering invites applications for a Post-graduate Scholarship to be awarded for the year 1956-57.

The objects of the Scholarship are to enable the holder:

(a) To pursue studies at post-graduate level directed towards some aspect of nuclear engineering, and

(b) To pursue an approved programme of research in some aspect of nuclear engineering.

The amount of the award will depend upon the circumstances of the successful candidate's case, but will usually be £350 per annum and will in no case exceed £400 per annum. The amount and duration will be assessed by the Selection Committee.

The normal duration of the Scholarship will be one year, or such longer or shorter period as may be approved.

Scholarships will be tenable at universities, technical colleges and other educational establishments (in the United Kingdom) approved by the Selection Committee.

GENERAL CONDITIONS

1. The candidate must be a British subject normally resident in the United Kingdom, with a university degree or its equivalent in engineering, physics, chemistry or metallurgy.
2. A candidate is required to submit a programme of work which he would undertake during the tenure of the Scholarship, together with an estimate of the cost of carrying it out, including personal expenses. Any other awards, allowances, etc., to the candidate, which would be concurrent with the Temple Press Scholarship, should be described.
3. The candidate is to furnish names and addresses of two referees who will be asked to advise the Selection Committee on the qualities of the candidate.
4. The award will be made at the absolute discretion of a Selection Committee.
5. The successful candidate shall devote his whole time to the programme of work proposed by him with such alterations as the Selection Committee may, with the candidate's agreement, approve at the time of the award.
6. At the completion of a Scholarship, a report is to be submitted, but the company may require interim reports on the work from time to time.
7. Prospective candidates may obtain forms of application from:

   The Editor,
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   All applications should reach the Editor by July 31, 1956.
8. Applications received will be considered by the Selection Committee, and a short list (if necessary) prepared of candidates required for interview by the Committee in London. Approved travelling and subsistence expenses will be defrayed by the Company.
9. The Selection Committee reserves the right to elect such candidates as it may approve and the grounds on which particular candidates have been elected or rejected need not be given.
10. In the case of an award for one year payments will be made as follows: October 1—one-half of award, January 1—one-quarter, April 1—one-quarter.
11. The Selection Committee may terminate a Scholarship at any time if it is not satisfied with the progress or conduct of the student.
12. Candidates should furnish evidence when required to the Committee that their programmes of work have the approval of the head of the institution or department in which they propose to work.

Comments on the News

THE KURCHATOV LECTURES

The timing of the lecture by M. Kurchatov at Harwell on April 25 can be considered as a masterpiece of international diplomacy. The comments made on progress in thermo-nuclear control created a prestige stir throughout the world, particularly in the United States where public opinion is forcing President Eisenhower to release more information on developments there. Although the lecture was sprung as a surprise and spontaneity of delivery was implied, it is perhaps significant that a full translation into English (neatly bound) was available before the lecture. However, whether the occasion was inspired by a sense of the dramatic or represented an honest desire for scientific collaboration it is sufficient to note that the days of national secrecy on such topics are disappearing once more and we can look forward to a time when technical matters at least are discussed openly by scientists of all countries. The easing of international tension that must inevitably result will be welcomed by all, irrespective of their orientation to the iron curtain.

WATER-MODERATED REACTORS

In many reports on the lectures too little emphasis was thrown on the final summing-up of the thermo-nuclear reaction experiments in which M. Kurchatov states quite specifically that the limit to this method of approach may have been reached and that there are serious reasons to believe that an increase in the temperatures achieved is not possible. At the same time the great importance of his discussions on the influence of the epi-thermal neutrons on water-moderated reactor calculations was left unnoticed.

Although M. Kurchatov described his presentation as painted in somewhat brighter colours because of the wariness of his audience in its approach to water-moderated reactors there can be little doubt that his calculations on the possible burn-up figures and the resulting economics of operation have left an impression.

We wonder whether the experience gained by the Soviet engineers will influence the proportion of time and effort that will be devoted to water-moderated reactor developments in the United Kingdom.

SOVIET REACTOR PROGRAMME

The paper on water-moderated reactors was preceded by a comprehensive survey of the Russian programme for power over the next 15 years. Initial projects envisage power stations of 400-600 MW installed capacity as representing the most economic system of generation.

In the years 1956-1960 five experimental stations are to be built the first of which will go into operation at the end of 1958. Two will comprise water-moderated and cooled thermal and epi-thermal 200 MW reactors feeding 70 MW turbines with saturated steam at 400 p.s.i. A second type will be built on the lines of the experimental power plant at the U.S.S.R. Academy of Sciences, using water cooling and graphite moderation to produce steam at 1,300 p.s.i. superheated to 500°C. Turbine capacity will total 200 MW. A third type will be heavy water-moderated, gas-cooled, producing steam at 400 p.s.i. at a temperature of 400°C and with a power output of 200 MW.

Over and above these five power reactors a number of pilot plants of 50 MW electric output rating will be built for feasibility studies on the direct turbine drive from a water-moderated, water-cooled thermal reactor, a homogeneous heavy water-moderated thermal breeder reactor with a U^{223}-thorium cycle, a graphite-moderated sodium cooled system and a fast sodium cooled breeder reactor using a plutonium uranium cycle.

A shortened version of the two papers presented appears on pages 101-106 of this issue.

STANDARDIZATION

The American Standards Association has already begun work on the establishment of national standards for the commercial and industrial use of fissionable material. Subjects within their jurisdiction include standards for nuclear safety, such as site location, transport, storage, radiation protection, symbols and colour codes, and terminology. Desirable as standards for reactor safety are, inevitably final decisions cannot be expected for some time and the art of designing reactors with safety considerations in mind will develop through the years and changes in these standards must be expected. This is not true for terminology and it is incumbent upon all who write and speak in the field of nuclear energy to develop a uniform language which is both explicit and comprehensive.

An example of misuse is in the phase "remote handling equipment" which at the present can refer to any of the three types in common practice, typified by tongs, mechanically linked implements and remotely controlled machinery. These can adequately be described as "extended," "articulated" (to describe apparatus used over and around shielding material) and "remote," to imply no direct mechanical linkage between the operator and the machinery (control being exercised by radio or direct electrical connection).

MANCHESTER N.E. COURSE

The Third Post-Graduate Nuclear Engineering Course at Manchester University began on May 22 and will continue until July 6. This course is similar to those held previously in Manchester and is designed as an introduction to the basic principles of the design of nuclear reactors and associated plant. The standard is intended to suit science and engineering graduates and although a university degree is not essential to acceptance for the course, students who have a good knowledge of engineering science are likely to derive most benefit from it.

Details of plans for future courses may be obtained from Mr. H. D. C. McLeod, Staff Officer, The University, Oxford Road, Manchester 13.

SMOKING CHIMNEYS

There appears to be an insistence from the artistic section of the community in its illustration of nuclear power stations on smoke being generated from the chimneys of Windscale and Calder Hall. The dire consequences of this happening in practice are not pleasant to contemplate and technical illustrators will be well advised to content themselves with a light heat haze at the most, not only because this is more accurate, but also because it is an important feature of a nuclear power station that it is smokeless and represents no particle pollution in the atmosphere whatsoever. The same cannot be said of even the most economically fired coal or oil burner.

INSTITUTION MEETINGS

At this time of the year when the Spring meetings of the institutions have been held and the close season in paper-reading has begun we can relax a little and look back on the value of the various meetings that have been held and the information that one has been able to cull from the papers presented. Undoubtedly if one is to keep abreast with progress in any field it is essential that a broad picture of the major developments should be acquired and this can be accomplished by attending the meetings of the various bodies.

Of equal value to the paper under discussion is the opportunity before and afterwards of meeting fellow workers in the field or visitors from allied fields to discuss topics of mutual interest.

As is natural papers are presented on the completion of a development project when the bulk of the loose ends have been tied up and where the method of attack has been worked out, often painfully, to a satisfactory conclusion. But as this work is complete it is unlikely that it is directly applicable to other problems and it is too easy afterwards to try and extrapolate the method of approach and as a result reproduce the type of dead-end investigations that have inevitably accompanied the original project.

There is thus frequently a greater interest in the methods of approach that have failed than in those that have been successful and probably more information can be learned from the reasons for these failures than from the results of the established line. Again in the successful approach quite often it is the minute details which are of direct assistance to the uninitiated rather than an account of the over-all project and usually because of the scope of the project these details cannot be given. There is no reason, however, why quite a number of these points cannot be brought out during the discussion periods provided that sufficient time has been left.

The practice has steadily increased whereby a completely formalized discussion time has been organized beforehand in which much time is spent on congratulating the speaker, delving into personal reminiscences and generally turning the meeting into a succession of after-dinner speeches. Desirable though it is for certain speakers to be primed to open the discussion these meetings are important occasions and much valuable time could be saved by omitting superfluous applause—if the speakers were not competent in their profession they would not be speaking. This is the time for delineating detailed points and asking leading questions to enable the speaker to point the avenues of investigation that were unproductive. At the same time speakers can be encouraged in the initial writing of the paper to go into details of their failures as well as their successes.

BRADWELL PUBLIC INQUIRY

The public inquiry into the proposed nuclear power station at Bradwell-on-Sea has shown that the fundamental objections to the construction and operation are not connected with the atomic energy side of the project but with the location of a generating station as such. Concern has been expressed that the livelihood of certain members of the community would be threatened by the deterioration in the oyster beds and that the increased temperature of the estuary might encourage the growth of the teredo worm.

As a relatively minor issue the point was raised that if the reactor is sufficiently safe in operation for it to be located in Essex then it is equally safe for a site in London. This is an argument that will be continually recurring and is of course entirely valid as far as it goes, but is certainly not applicable when the power is required in Eastern England. Much patience must be exercised in emphasizing the advantages of semi-remote sites for the construction of these first installations and in pointing out the greatly increased ease of checking a sparsely populated neighbourhood; quite apart from the less serious consequences of a major accident which —let's face it—although extremely remote cannot be ruled out entirely. We must be prepared to take some risks in life and if these never exceed those of simply living near a reactor then we shall pass reasonably tranquil lives.

In the words of A. S. McLean, "the crux of the situation today is the need to accept atomic energy as an essential part of the background to our lives, to understand its problems and eventually to invest it with the atmosphere of tradition."

FLUORESCENT LIGHTING

In answer to some of the questions posed at the end of his lecture on "Some Problems in Maintenance of Nuclear Reactors" on May 3, Mr. Davey, general manager of the Windscale works, emphasized the problems of inspection and surveillance of remotely controlled work by means of the introscope and television camera. With the narrow access holes that have been provided in reactors built to date a minimum of three holes has been required to carry viewing equipment, lighting assembly and the operating tool. Inevitably, therefore, much of the work is in shadow and only a small area can be covered at any one time. In view of the intense activity of the parts under inspection thought should be given to the use of fluorescent materials which can be either painted on, or incorporated in the original constructional materials. Little effort has been devoted to the production of phosphors which fluoresce under beta and gamma radiation (except of course for scintillation counting) as for luminous clocks, watch dials, meters, etc., an alpha activating agent can be used. If, however, fluorescent paints could be developed in various colours which are sensitive to beta and gamma radiation, the problem of lighting inside a reactor shield would be considerably reduced. The use of colours is desirable to point differing constructional materials and significant structural features.

DEVELOPMENT COSTS

A number of companies in the United States have recently been at pains to emphasize the vast expenditure that is required before private nuclear power plant business can become a profit making activity, for example Westinghouse Corporation, at present employs 1,000 professional people in this field and has already earmarked $20m. for equipment and facilities. Estimates of the General Electric Company allocation are in the region of $15m. Monsanto Chemical Co. was forced to abandon its project on a breeder reactor at the end of last year due to the withdrawal of A.E.C. backing after spending more than a million dollars.

CURRENTS AND BOTTLES

A new interest will be added to the summertime pursuit of picking up bottles on the beach and looking for messages, by the decision of the Japanese Oceanographic Society to unload 10,000 bottles from Japanese ships in the Pacific, each containing a post-card addressed back to Japan. This is in an attempt to plot the ocean currents passing through the area of the American atomic weapons testing ground, by tracing the progress of the "dead marines."

Some doubt must be thrown on the validity of the results so acquired. In mid-ocean at least the bottle concentration is normally not high and the behaviour of additive bottles cannot therefore be regarded as typical of the surrounding medium. An important characteristic of the average bottle is that it either sinks or swims and those recovered will have been influenced only by the superficial currents. A further serious limitation to the system is imposed by the non-isotopic nature of bottles and the absence of exchange characteristics.

Clad Steel Plates

Considerable economies can be made in the handling of corrosive fluids by the use of standard constructional metals clad with corrosion resistant materials. Fabrication with stainless steel and nickel clad plates requires only minor modifications to established practice.

by
JOHN ERSKINE, B.Sc., A.I.M.
Colclad Department, Colvilles Ltd.

THERE is an increasing demand for structural materials which will withstand the attack of a variety of corrosive media, the best known in this category being the stainless steels containing either 12 or 14% chromium or the so-called 18/8 type containing 18% chromium and 8% of nickel; the latter is used for the more severe conditions of service. Other materials, such as pure nickel or Monel—made by Henry Wiggin and Co. Ltd.—are also in demand for specialized applications.

In the main, these materials are used in the form of plates for the construction of containers, pressure vessels, autoclaves, and so on, where one surface only is in contact with the corrosive medium. Satisfactory service behaviour and life can be obtained, in most cases, by confining the corrosion-resisting metal or alloy to the surface of the plate where it is required, using other more suitable types of structural steel for the backing plate to provide strength.

Ordinary structural mild steel is usually adequate for the backing plate, but occasions arise when special properties such as enhanced resistance to creep at elevated temperatures is necessary, in which case one of the molybdenum or chrome-molybdenum steels, for example, may be used. Thus clad plates offer the possibility of useful combinations of properties which open up new avenues of application.

Other advantages of clad plates are their availability in greater weights and dimensions than is the case for some of the special corrosion-resistant materials, and also their relative cheapness. Finally, they have an important contribution to make to the national economy by conserving alloys. Where nickel-bearing steels of the 18/8 type, for example, are involved, the current shortage of nickel, which is likely to persist for some time, is a forceful argument in favour of clad steels because, apart from the question of cost, their extended use would play an important part in conserving what nickel there is available.

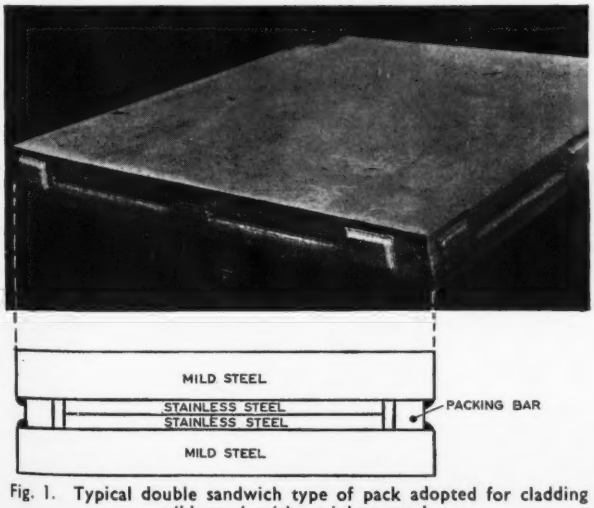

Fig. 1. Typical double sandwich type of pack adopted for cladding mild steel with stainless steel.

A desirable, and in many cases an essential feature of cladding is a continuous and efficient bond between the two metals so that they will not come apart during subsequent fabrication of the plates or in service. This bond is usually effected by hot rolling a composite slab in a plate mill. The two dissimilar metal surfaces are brought into contact and forge welded together under the influence of temperature and pressure. Oxide scale formation at the high temperatures involved is prevented by sealing the edges of the pack by welding using ordinary mild steel electrodes.

The simplest form of composite pack consists of a relatively thick mild steel slab covered by a thin plate of the cladding metal, but there are several reasons why this procedure is not generally adopted. In cladding mild steel with stainless steel of the 18/8 type, for example, the difference in the coefficient of expansion makes this procedure impracticable. For this and other reasons, it has been found advantageous to adopt a double sandwich type of pack, by means of which clad plates are produced in pairs simultaneously. The construction of a typical pack is illustrated in Fig. 1, from which it will be observed that accommodation is provided for differential expansion between the cladding insert plates and the slabs of backing steel. Welding of the two cladding insert plates to each other is prevented by the presence of a thin film of refractory material applied in the form of a paste.

The production of nickel-clad plates is on these lines, and provided that the two surfaces are clean, there is no difficulty in getting an efficient bond between the nickel and mild steel during hot rolling. In the case of stainless steels, however, the relatively high content of chromium creates a problem. Such steels owe their stainless properties to a sub-microscopic surface film of chromium oxide. Unfortunately the presence of this film makes forge welding in the hot rolling process difficult and uncertain. Many methods have been proposed for overcoming this difficulty, but only a few have proved successful for the bulk production of large clad plates.

In the Colville process for the manufacture of the Colclad range of clad steels, advantage is taken of the fact that the chromium oxide layer which prevents forge welding of stainless steels does not prevent welding with the electric arc. Therefore, arc welding is adopted in a separate stage of the process, which provides stainless steel insert plates, one surface of which is coated with a thin veneer of mild steel. This is economically accomplished by arc-welding a layer of mild steel on to one surface of the stainless-steel slabs prior to hot rolling in the normal manner in a plate mill. The deposition of the mild steel is carried out rapidly and efficiently using the Lincold Spreadarc process as illustrated in Fig. 2. Such specially prepared stainless-steel insert plates can be readily bonded to the mild steel slabs when inserted in the composite pack already described. These packs weigh up to 10 tons and vary in total thickness from 4 in. to 12 in.

By adjusting the relative thickness of the mild steel and the insert plates, clad plates can be produced with a wide range of cladding thicknesses, although it is usual for plates with an overall thickness of ½ in. to have 20% cladding whereas over this thickness the percentage of cladding is normally about 10. Uniformity of cladding thickness is, of course, an

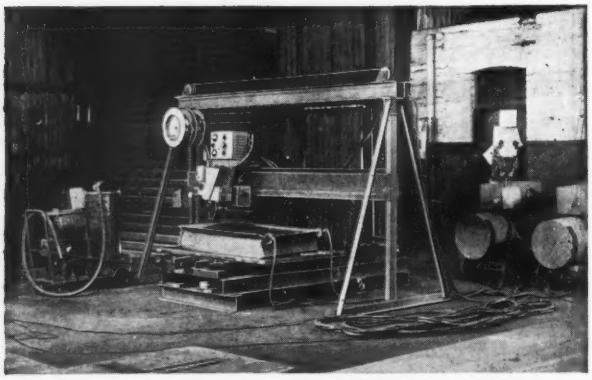

Fig. 2. Lincold Spreadarc equipment for the deposition of mild steel on the stainless-steel insert plates.

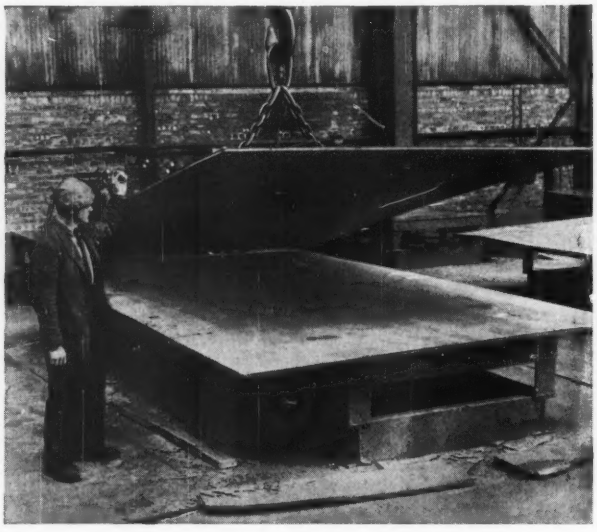

Fig. 3. Separating the pair of clad plates rolled from the pack.

important consideration, and the clad surface should obviously be smooth and regular. In this respect, the method of rolling from the double sandwich packs where the cladding material is protected from the furnace atmosphere and from contact with the rolls in the mill, has many advantages.

The pair of clad plates rolled from the pack are separated as illustrated in Fig. 3 when the edge and side scrap are removed by shearing or gas cutting. Before separation, however, plates may be heat-treated to give the optimum mechanical properties, the nature of the heat-treatment depending on the types of backing plate and cladding involved. Heat-treatment at this stage is an obvious advantage, as the surface of the cladding is protected from the furnace atmosphere.

The process has now been in use for several years, during which time about 8,000 tons of clad plates of various types in thicknesses from $\frac{1}{16}$ in. to 4 in. have been delivered to the home and export markets. Typical chemical analysis of the various types of cladding used to date is given in Table I.

Mechanical Properties

In the tensile test, the clad plates disclose no abnormal features, the results obtained being as predicted from the known tensile properties of the backing plate and the cladding. In carrying out the test, there is no evidence of separation and the ductility as denoted by percentage elongation or reduction of area is excellent. Typical tensile test results for stainless clad plates are shown in Table 2.

For certain applications such as pressure vessels, etc., it is most desirable to have a bond of uniform strength and ductility, and this is a characteristic of plates produced by this process. The average value obtained for the shear strength of the bond is 40,000 lb. per sq. in. The efficiency of the bond is further demonstrated by the results of cold bend tests with the cladding either in compression or tension as illustrated in Fig. 4. Such tests are carried out as a matter of routine on every clad plate.

To test the efficiency of the bond over the entire area of the plate, Colvilles have developed an ultrasonic testing technique. The general principles involved in ultrasonic testing are well known. The most common method is the echo technique which makes use of the fact that ultrasonic waves are reflected at discontinuities in any material through which they are passed. Thus by observing on an oscillograph the reflections of a suitable ultrasonic wave pulse, defects may be detected. In the special technique employed, a 2 megacycle single transceiver probe is used and pulses of ultrasonic waves are transmitted into the plate from the clad side. Typical oscillograph records from sound and defective areas are shown in Fig. 5.

To increase the speed of testing, the probe is mounted on a wheeled trolley which is rolled over the plate, water being used as a contact medium. A further aid to rapid testing is an automatic device which is set to detect the alteration in

Fig. 4. Typical tensile-test specimens of stainless-steel clad plates after bending.

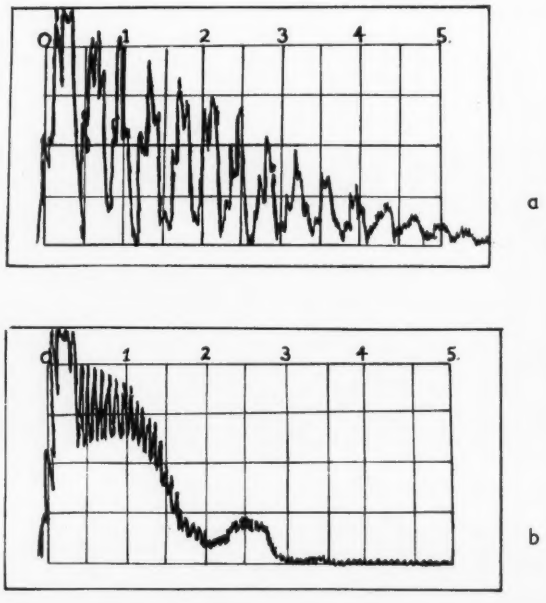

Fig. 5. The bond is checked by ultrasonic testing methods. These oscillograph patterns show (a) sound area, and (b) defective area.

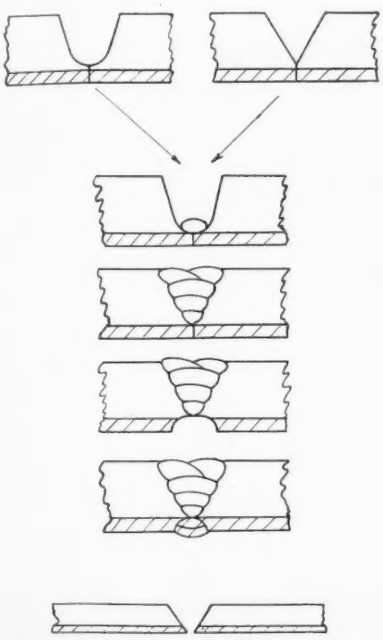

Fig. 6. Recommended edge preparations for welding. The upper illustrations apply to heavy gauge plate, whilst the bottom one is for plates up to $\frac{5}{16}$ in. thick.

TABLE 1

Type	Carbon %	Nickel %	Chromium %	Molybdenum %	Niobium %	Titanium %	Aluminium %	Copper %
14% Cr.	0.08	0.50	13.8	—	—	—	—	—
14% Cr. + Al.	0.07	0.59	12.5	—	—	—	0.28	—
18/8 Ti.	0.06	9.1	18.6	—	—	0.32	—	—
18/8 Cb.	0.05	9.6	19.1	—	0.59	—	—	—
18/10/2 Cb.	0.06	12.3	19.3	2.28	0.40	—	—	—
18/10/2 Ti.	0.06	12.1	19.6	2.38	—	0.30	—	—
L. Nickel	0.02	99.0	—	—	—	—	—	—
AT Nickel	0.10	99.0	—	—	—	—	—	—
Monel	0.14	67.0	—	—	—	—	—	30.0

TABLE 2

Total thickness of clad plates	Thickness of cladding	Quality of cladding	Quality of backing steel	Max. stress tons/sq. in.	Elong. % 8 in.
3/16 in.	20%	18/10/2	0.15% C Steel	31.9	25.0
1 in.	12.5%	14% Cr.	0.5% Mo. Steel	29.8	26.0
1¼ in.	8.0%	14% Cr.	0.25% C Steel	34.8	25.0
1½ in.	10%	18/8 Cb.	0.15% C Steel	31.0	25.0
2 in.	12.5%	14% Cr.	0.15% C Steel	28.4	25.0

oscillograph pattern produced by a defect. An audible warning signal is given when a flaw is located, relieving the operator of the need for constant observation of the oscillograph screen. Using this method, testing speeds of about 160 sq. ft. per hour are now being obtained.

Fabrication

Gas Cutting.—One of the advantages of clad steels over solid plates of the special materials is that this operation can be carried out with the same equipment as is used for mild steel. There is no need to use powder cutting or other specialized stainless-steel cutting techniques. Clean, smooth cuts can be obtained provided that the cutting is done with acetylene gas and from the mild steel side. The molten mild steel provides the flux required to melt the alloy cladding. As possibly 80% of the plate thickness is mild steel, flame bevelling, where favoured, can be used to prepare the edges for welding.

Shearing.—Where shearing is the method of cutting used, then the stainless surface must be uppermost so that the shearing barb is thrown on to the backing plate side.

Hot Working.—In most fabricating shops hot pressing forms an essential part of the work, and any constructional material offered to the fabricator must be capable of hot working. In the severe conditions of hot pressing and spinning, clad plates do not present any problem. Due to the fact that one surface is of a special material, such precautions as would normally be taken with a homogeneous plate of this material must also be taken with clad plates. These precautions refer especially to heating conditions and maximum hot working temperatures. The former is particularly important when heating nickel or Monel clad plates. In such cases precautions must be taken to ensure that the furnace atmosphere is low in sulphur and sulphur compounds, otherwise serious embrittlement of the nickel or Monel surface can occur.

Cold Forming.—Rolling to shape as for vessel shells presents no difficulty provided that allowance is made for greater spring-back of clad steels over mild steel. If severe cold forming operations are to be carried out, then intermediate heat treatments should be given.

Welding.—To the fabricator, ease of welding is a point of major importance. As approximately 80% of the total plate thickness is mild or low alloy steel, high-grade mild steel or low alloy electrodes can be used for the bulk of the joints except where the plates are extremely thin. Strict attention must be paid to accuracy of edge preparation and alignment. Some recommended edge preparations are illustrated in Fig. 6. Welding commences from the mild steel side. After completion, the final sealing runs must maintain the continuity of the cladding surface, electrodes of the corresponding quality being used. Before commencement of this sealing weld, the clad side of the joint is thoroughly cleaned by grinding or chipping to sound weld metal. The depth of this grinding need not be more than 50% greater than the cladding thickness. In the case of stainless steel, the root runs are made with a 25/20 or 25/12 type of electrode, thus minimizing the effect of dilution from the mild steel side. The final runs are made with an 18/8 type of electrode. For the thinner gauges of stainless steel clad plates up to, say, $\frac{1}{16}$ in., it is usual to use 25/20 chrome nickel electrodes throughout for the joint.

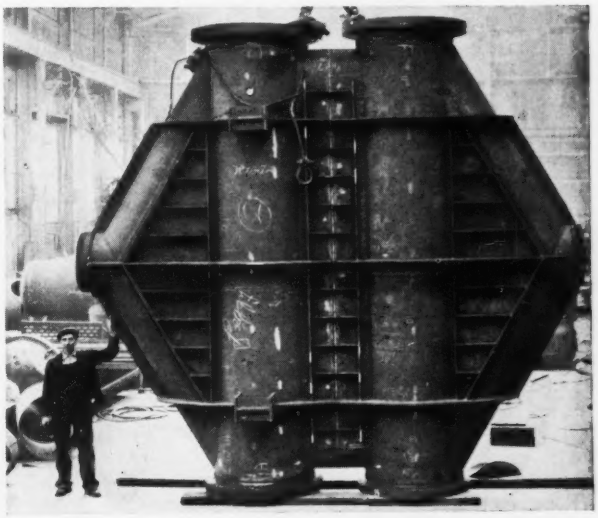

Fig. 7. Heat exchanger in Colclad 14% Cr stainless steel built by Henry Balfour and Co. Ltd.

Whilst as a general rule in the welding of clad steels the electrode used for the cladding side of the joint gives a deposit which matches as closely as possible the chemical composition of the cladding, there is, however, an exception to this rule in the case of 14% chrome cladding. Because of the brittle nature of the weld deposit of this composition, a 25/20 austenitic type of electrode is used.

Internal Stresses

Due to different expansion coefficients of carbon steel and 18/8 types of stainless steel, internal stresses must be induced under service conditions involving temperature variations. So far as the bond is concerned, these stresses have proved to have no harmful effects in service. This has been confirmed by laboratory experiments in which fabricated rings with cladding both on the outside and inside were heated to 450 °C and quenched in water at hourly intervals. After 3,000 such reversals, the bond between the cladding and backing plate was still intact.

The final proof of any new product is its behaviour in service. Colclad plates have been supplied to all parts of the world and are in service in many different kinds of corrosive media and temperature conditions.

There has not been a single instance of service failure, from which it can be concluded that clad plates are capable of adequately fulfilling their service requirements. Some typical units are illustrated in Figs. 7 and 8.

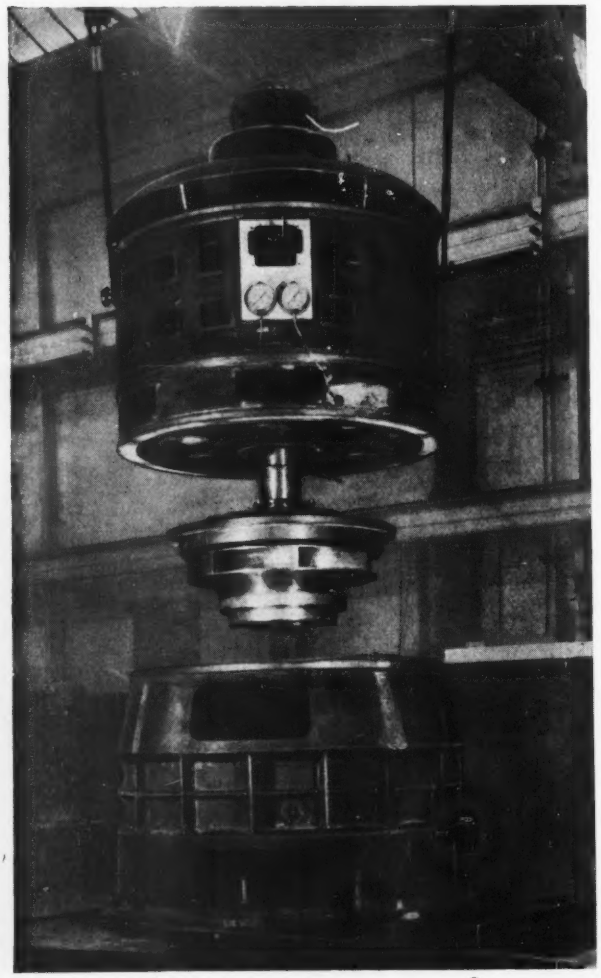

Fig. 8. The body of this Harland Electroglide pump is fabricated from Colclad 18/10/2Cb plates.

Les Tôles d'Acier Revêtues Inoxydables

La construction de grandes installations qui nécessite l'emploi en grand de matériaux de construction inoxydables comme l'acier chromé (12 *ou* 14%) *ou l'acier inoxydable* 18/8, *a augmenté l'interêt d'aciers revêtus pour lequels le matériau de revers habituel est l'acier doux. Les deux surfaces métalliques dissemblables sont mis en contact et soudées à forge sous l'influence de température et de pression. La formation d'oxyde est empêchée en scellant les bords du paquet par le soudagé. Jusqu'à présent à peu près* 8,000 *tonnes de tôles revêtues ont été produites par Colvilles Ltd., en épaisseurs de* $\frac{3}{16}$ *à* 4 *pouces. Le valeur moyenne de résistance au cisaillement du lien est à peu près* 20 *tonnes par pouce carré.*

Les tôles revêtues peuvent être coupées à gaz avec l'acétylène du côté de l'acier doux, l'acier doux lui même remplissant les fonctions de flux. Pour le cisaillement la surface de l'acier inoxydable doit être en dessus. Les tôles peuvent être travaillées à chaud pourvu qu'on presne les mêmes précautions que dans le cas d'une tôle composée du plus difficile matériau des deux. Le soudage ne présente pas de problèmes, pourvu qu'on apporte du soin à la préparation des bords et qu'on utilise sur le côté revêtu des electrodes spéciales pour éviter la fragilité excessive.

Nichtrostende mit Schutzschicht versehene Stahlplatten

Der Bau einer grossen Anlage bringt einen grossen Bedarf nichtrostender Konstruktionsmaterialien mit sich, wie z.B. 12% *oder* 14% *Chrom oder* 18/8 *nichtrostender Stahl und hat dadurch das Interesse an Stahl mit Schutzschichten erhöht; dabei ist das am meisten verwendete Grundmaterial weiches Stahlblech. Die beiden verschiedenen Metallflächen werden miteinander in Berührung gebracht und unter Druck bei erhöhter Temperatur verschweisst. Die Bildung von Oxyden wird durch Absiegelung der Kanten des Blechpaketes mittels Schweissens verhindert. Bisher sind rund* 8000 *Tonnen mit Schutzschicht versehener Platten von Colvilles Ltd. produziert worden in Stärken von* $\frac{3}{16}$ *in. bis* 4 *in.* (4,76-103 *mm.*). *Der Mittelwert der Scherfestigkeit des Verbandes ist ungefähr* 20 *tons/sq. in.* (3150 *kg/cm.*^{2}).

Die mit der Schutzschicht versehenen Platten können mit Azetylen von der Eisenseite her geschnitten werden, wobei das geschmolzene Eisen selbst als Flussmittel dient. Beim Abscheren muss die rostfreie Stahlfläche oben liegen. Die Platten können warm verarbeitet werden, vorausgesetzt dass dieselben Vorsichtsmassnahmen getroffen werden, die man anwenden würde, wenn die Platte aus dem schwierigerem der beiden Materialien bestände. Schweissen ist kein Problem, vorausgesetzt, dass bei der Vorbereitung der Kanten sorgfältig verfahren wird, und dass bei der Fertigbearbeitung auf der geschützten Seite spezielle Elektroden verwendet werden, um unzulässige Sprödigkeit nicht aufkommen zu lassen.

Planchas de Acero Revestidas para Resistencia a la Corrosión

La construcción de una gran planta que implique el empleo en gran escala de materiales de construcción no corrosivos, tales como cromo del 12 *o* 14%, *o acero inoxidable* 18/8 *ha aumentado el interés en los aceros revestidos, para los cuales el material más corriente de respaldo es el acero dulce. Se hace que estas dos superficies dispares de metal entren en contacto y se sueldan a forja bajo la influencia de la temperatura y de la presión. Se impide la formación de óxido sellando los bordes del empaque por soldadura.*

Hasta le fecha se han producido por Colvilles Ltd., unas 8.000 *toneladas de planchas revestidas, con espesores desde* $\frac{3}{16}$" (4,76 *mm.*) *hasta* 4" (103 *mm.*).

El valor promedio de potencia absoluta de trabazón es de aproximadamente 20 *toneladas por pulgada cuadrada.*

Las planchas revestidas pueden ser cortadas al acetileno del lado de acero dulce, actuando el acero dulce derretido mismo de fundente. Para cizallamiento, la superficie de acero inoxidable tiene que estar para arriba. Las planchas pueden ser trabajadas en caliente siempre y cuando se adopten las mismas precauciones que se adoptarían para el labrado de una plancha compuesta del más difícil de los dos materiales. La soldadura no ofrece problema alguno, siempre que se tenga cuidado en la preparación de los bordes y que, en el acabado del lado revestido, se empleen electrodos especiales para evitar que se vuelva excesivamente quebradizo.

Physics of the Water-Moderated Reactor

In the first of the two papers presented by the Soviet Academician to a group of scientists at A.E.R.E., Harwell, the physics of water-moderated reactors is discussed with particular emphasis on the role played by epithermal neutrons.

by
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WATER-MODERATED reactors are simple and compact in design and have a high breeding ratio. In our opinion, they have a great future in the field of large-scale atomic power-production.

The physics of thermal and fast reactors is now relatively well known. This cannot be said of water-moderated reactors because of the great influence of epithermal neutrons on the physics calculations. In the uranium-water lattice, a relatively large fraction of the neutrons can be absorbed with multiplication in the energy range between approximately 0.1 and 3-5 ev; that is above the thermal energies and below the U 238 lower resonance levels. This fraction, depending on the parameters of the lattice and burn up, can be as high as 80%.

In its simplest form the theory of a reactor in which a noticeable part is played by epithermal neutrons was given by Prof. Feinberg in his paper at the July 1955 session of the U.S.S.R. Academy of Sciences. In his calculations, he proceeded from the elementary moderation theory, neglecting the chemical bond between the moderator protons. Nevertheless, this approach makes it possible to ascertain the fundamental qualitative features of the epithermal reactor. They are due, chiefly, to the strong resonance peak in the neutron cross-section of Pu 239 at 0.3 ev.

As long as there is no plutonium in the reactor core, the calculated lattice multiplication factor depends only slightly on the epithermal neutron absorption. At high uranium burn up, however, when a considerable quantity of plutonium accumulates, it is important to consider the epithermal region although η for plutonium is lowered at resonance 0.3 ev, $k\infty$ increases with epithermal capture. By way of illustration, let us consider a 50-mm. spaced lattice of metal lumps of enriched uranium and U 238 and Pu 239.

As the following table shows, epithermal neutron capture is highly important for the achievement of a high uranium burn up in a water-moderated reactor.

TABLE 1.

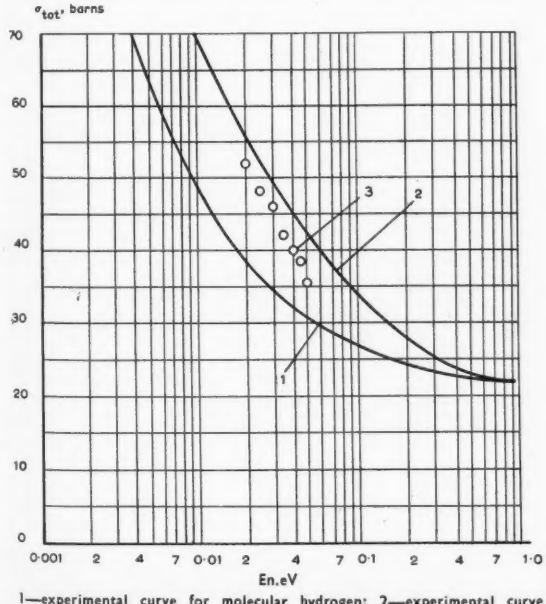
Lump composition	$k\infty$	
	without considering epithermal capture	considering epithermal capture
0.9% U 235 + 99.1% U 238	1.079	1.047
0.73% Pu 239 + 99.27% U 238	1.079	1.272

The value of η for plutonium in the epithermal region, especially at its lower boundary, strongly depends on neutron energy. Therefore, it is important to know in detail the neutron spectrum and, first of all, to ascertain to what extent the elementary theory yields true solutions.

To provide an accurate calculation of the neutron spectrum formation process in the energy range of interest to us, it was necessary to study the mechanism of neutron collision with protons chemically bound in the water molecule. Theoretical investigations carried out by Drozdov and Goryunov have made it possible to ascertain the energy dependence of neutron elastic and inelastic scattering cross-sections of hydrogen and water molecules at energies below 0.5 ev. The calculations assumed neutron scattering on free hydrogen and water molecules and took into account the molecules' rotational and vibrational levels. Fig. 1 shows some of these results. Wherever possible, the theoretical values have been compared with experimental data.

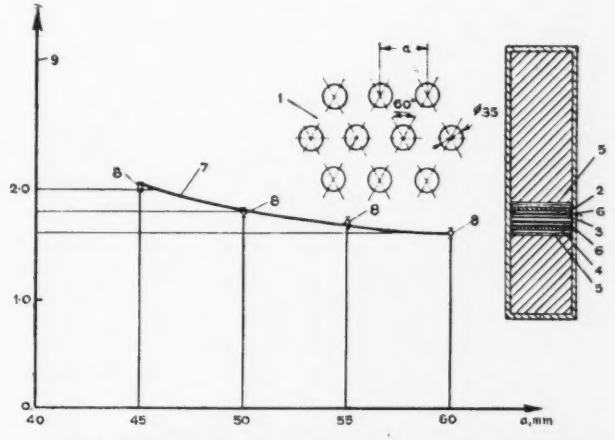
A check on the elementary theory was to determine the major characteristics of the processes occurring in the epithermal region and to compare them with the calculations.

Stolyarov, Nikolsky, Katkov and Antsiferov irradiated targets of thin Pu 239 and U 235 layers deposited on thin nickel foils. The targets were placed in the slits of the lumps of the sub-critical uranium-water lattice (Fig. 2). The relative changes of the Pu 239 and U 235 cross-sections as a function of the lattice neutron spectrum hardness was determined by the activity of the fission products collected on paper discs. In Fig. 2, the experimental data



1—experimental curve for molecular hydrogen; 2—experimental curve for water; 3—Goryunov calculated values.

Fig. 1. Comparison of experimental and calculated values of total bound hydrogen neutron cross-section.



1—sub-critical uranium-water lattice of natural uranium lumps 35 mm in diameter with "a" spacing. The sub-critical lattice dimensions much exceed the neutron migration length; 2—nickel foil with deposited layer of PU 239; 3—paper disc for background determination; 4—nickel disc with deposited layer of U 235; 5—copper discs for shielding against fission fragments; 6—paper for collecting fission fragments; 7—theoretical curve; 8—results of experiment by Stolyarov, Nikolsky, Katkov and Antsiferov; 9—ratio σ^f PU 239/σ^f U 235 in arbitrary units.

Fig. 2. Neutron cross-section of Pu 239 and U 235 in sub-critical uranium-water lattice.

are compared with Feinberg's calculations. These data, of course, cannot be regarded as proof that the elementary theory of moderation is true to fact. They show, however, that this theory has practical value for evaluating the problem of high burn-up in a water-moderated reactor. The moderation length measurements from the first indium resonance energy to the thermal energy, carried out by Barkov and Mukhin, indicate no great dependence of the neutron shift in the moderation process on the chemical bond.

Kommissarov, Tarabanko and Katkov, by measuring U 239 production, have experimentally determined the Pu 239 breeding ratio at the initial moment of reactor operation, i.e., when there is as yet no Pu 239 in the core. Fig. 3 gives the experimental and calculated values of the breeding ratio as a function of lattice spacing. The agreement with the calculations may in this case also be considered satisfactory.

On this basis, Feinberg, Levina, Osmachkin, Novikov and Saulyev, using Acad. Lebedev's electronic computer have made a set of calculations of high burn-up in uranium-water lattice. For these calculations, they used the nuclear constants obtained by Mostovoi, Pevzner and collaborators with a velocity selector; and by Spyvak, Yerozolimsky, Kutikov, *et al.*, with a graphite pile. For the solution of these problems, it is quite important to take into account the neutron absorption in the accumulating Pu 240. The results of the calculations noticeably depend on the adopted nuclear constant values and assumptions concerning the spectrum form of the absorbed neutrons.

The nuclear fuel recirculation process, i.e., the sequence of the burn-up cycle in the uranium-water lattice, is of great interest in the U 238 burn-up problem. There are perhaps grounds for expecting that the uranium-water lattice will permit, in the nuclear fuel recirculation process, full utilization of the U 238. Considering the inevitable and substantial losses of nuclear fuel in the numerous chemical and metallurgical processings, the possibilities of the uranium-water lattice approach those of fast breeder-reactors. The further refinement of the constants, a more detailed study of the moderation processes and, what is most important, investigation of water-moderated reactors with large accumulations of Pu 239, will make it possible to reach accurate conclusions on this important question.

In view of the possibility of high uranium burn-up, even in one cycle, fabrication of a fuel element capable of long service under radiation becomes of great practical importance.

We believe that sintered uranium dioxide, due to its stability under irradiation and insolubility in hot water, is an excellent material for a uranium-water lattice. Our long experiments with the PTR reactor have shown that even with a non-sealed cladding, the uranium dioxide lumps work satisfactorily: there is no contamination of the circuit with fission products, the small gas activity rapidly disappears after reactor shut-down.

The dioxide considerably reduces the uranium-water lattice breeding ratio. Therefore, we continue the work of developing stable lumps of metal uranium. After a number of failures, a group of Soviet scientists and engineers succeeded in developing the technology of manufacturing good metal lumps. With a burn-up of 3 kg per ton, such lumps still do not show any change of form, and it is quite possible that in the future, metal uranium may be used in the uranium-water lattice.

In conclusion, I would like to dwell on the use of ordinary water in thorium systems.

The problem of breeding in the U 233-thorium cycle in heavy water moderated thermal reactors and fast reactors, has been discussed time and again. In our institute, investigations have been carried out by Feinberg, Kunegin and Nemirovsky which show that by using ordinary water as moderator in a U 233-Th system, it is possible to obtain a breeding ratio close to 1.2 and, thus, achieve the complete thorium burn up.

A reactor of this type should consist of a core with laminated fuel elements containing U 233 and surrounded by a breeder blanket containing Th or ThO_2 lumps. This heterogeneous reactor used as moderator ordinary water at a temperature of 300°C and a pressure of about 100 atm., flowing between the laminated fuel elements with a very high surface heat rate.

Evaluation of the possibilities of such a system is based on calculations of the breeding ratio at different water-to-U 233 ratios in the lattice, with different quantities of structural materials. Aluminium, zirconium, stainless steel, etc., were considered as such materials. An essential property of the thorium system is that η of U 233 is practically constant and equals 2.3 over a rather wide energy range (Table 2).

TABLE 2.

η-dependence on neutron energy for U233*

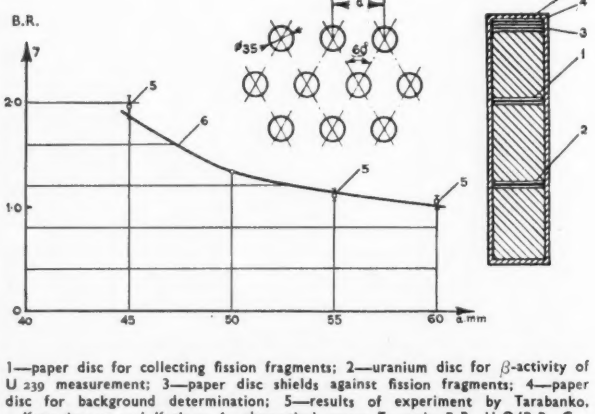
Neutron energy region		η	Neutron source
Thermal		2.28 ± 0.02	Spectrum parts separated by filters
0.15-0.5 ev		2.28 ± 0.09	Same
0.4-3	,,	2.24 ± 0.05	,,
0.6-6	,,	2.24 ± 0.05	,,
2.5-25	,,	2.28 ± 0.05	,,
8-130	,,	2.28 ± 0.05	,,
30	kev	2.25 ± 0.07	Photoneutrons
140	,,	2.43 ± 0.12	,,
250	,,	2.45 ± 0.12	,,
900	,,	2.60 ± 0.13	,,

* Data obtained by Spyvak, Yerozolimsky, Dorofeyev, Lavrenchik, Kutikov, Dobrynin.

The nuclear fuel breeding ratio $B.R.$ can be described by the following simple formula:

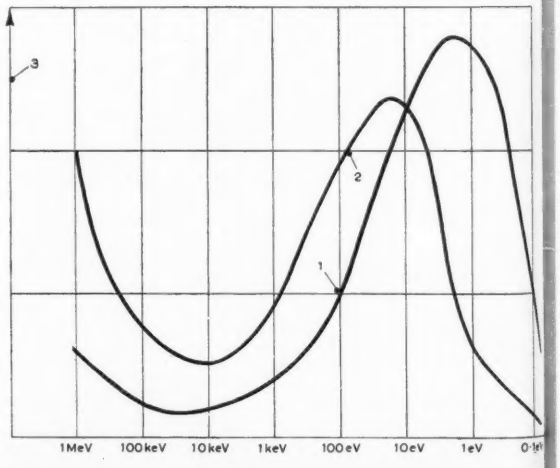
$$B.R. = \eta - 1 - \delta,$$

where δ is the part of the neutrons that is lost in water, in structural materials, in accumulating fission products, in the blanket and due to the accumulation of uranium isotopes with mass 234, 236 and even 235.



1—paper disc for collecting fission fragments; 2—uranium disc for β-activity of U 239 measurement; 3—paper disc shields against fission fragments; 4—paper disc for background determination; 5—results of experiment by Tarabanko, Kommissarov and Katkov; 6—theoretical curve; 7—ratio B.R. H_2O/B.R. C

Fig. 3. Sub-critical uranium-water lattice breeding ratio (B.R.).



1—for ratio 20:1; 2—for ratio 5:1; 3—neutron absorption density to arbitrary scale.

Fig. 4. Neutron absorption spectrum in the reactor in dependence on the hydrogen-to-uranium atom ratio.

The value δ strongly depends both on the shape of the neutron spectrum in the reactor and on the nuclear fuel burn up in one cycle.

Neutron losses in water and in structural materials decrease with the amount of water and structural materials in the lattice. When the hydrogen-to-U 233 atom ratio α changes, within the range of 20 to 1, the losses are rather small, and the neutron absorption spectrum in the reactor core is rather hard even when α equals 20 (only a very small percentage of the total number of neutrons absorbed in the lattice reach the thermal region) and is close to the spectrum of a fast reactor at $\alpha=2$ (Fig. 4). When α has this value, Xe 135 poisoning is much smaller than in thermal reactors.

U 234, U 235, and U 236 may considerably contribute to δ. When the burn-up is 30%, U 234 accumulated in one cycle comprises about 3%. The amount of U 235 accumulated in one cycle will be $\sim 0.5\%$. Since the resonance integral of U 234 is evidently at least one-fifth of the resonance integral of U 233, the latter's contribution to δ does not exceed 0.005. As time goes on, an increasing number of other uranium isotopes will be accumulated in U 233, in all subsequent burn-up cycles. If we examine the stationary state of the system which will set in after a considerable period of time, and if we assume η 235 to be equal 1.5 (see Table 3), for epicadmium neutrons, then δ will not exceed 0.2. It may be reduced by separating U 233 from the uranium isotope mixture. This method seems to be technically and economically advisable, because the quantity of uranium processed in the isotope separating plant is relatively small.

TABLE 3.

η-dependence on neutron energy for N235*

Neutron energy region	η	Neutron source
Thermal	2.06 ± 0.02	Spectrum parts separated by filters
0.15-0.5 ev	2.06 ± 0.06	Same
0.4-3 "	1.60 ± 0.04	"
0.6-6 "	1.50 ± 0.04	"
2.5-25 "	1.52 ± 0.04	"
8-130 "	1.48 ± 0.04	"
30 kev	1.86 ± 0.04	Photoneutrons
140 "	2.12 ± 0.10	"
250 "	2.2* ± 0.15	"
900 "	2.28 ± 0.08	"

* Data obtained by Spyvak, Yerozolimsky, Dorofeyev, Lavrenchik, Kutikov, Dobrynin.

Thus, the breeding ratio in the U 233-Th cycle; that is an epithermal reactor, can range from 1.10 to 1.20, with the burn-up in one cycle being 30%.

For the economical production of nuclear power, it is necessary to have, besides a high breeding ratio, a high specific heat capacity per unit of nuclear fuel weight. When ordinary water is used as moderator, the heat capacity per unit of reactor core volume can reach 1,000-2,000 kW per litre, if a specific heat capacity is 2,000-5,000 kW per kilogram of nuclear fuel.

Such values are characteristic also for fast reactor cores. This type of reactor, however, has one advantage. The nuclear fuel in it can be diluted by a considerable quantity of structural materials, such as aluminium, for example, with practically no noticeable loss of breeding ratio, which simplifies the problem of creating long-living fuel elements. It should be noted that thorium behaves much better in the reactor than uranium. Even with large accumulations of U 233 in thorium, there was not a single case of thorium lump failure or any changes similar to those which are well known for uranium.

Thermo-Nuclear Experiments

The second paper by I. V. Kurchatov on experiments made with a view to producing temperatures at which a thermo-nuclear reaction could be expected to take place whilst concluding that the method of approach used is unlikely to yield a final solution represents the first major publication on the subject.

As is well known, thermo-nuclear reactions can arise if the temperature of matter is sufficiently high for atomic nuclei to surmount with appreciable probability the forces of the Coulomb barrier during thermal collisions. The excitation of the thermo-nuclear reactions in deuterium or in a mixture of deuterium and tritium is especially interesting as in this case a noticeable effect should be obtainable at relatively low temperatures.

The intensity of thermo-nuclear reactions in deuterium should greatly increase with the temperature up to temperatures of several billion degrees.

An estimate regarding the conditions under which thermo-nuclear reactions should be experimentally observable can be obtained by considering some concrete cases.

In deuterium, whose density is nearly unity under normal conditions, a temperature of 2.10^5 degrees would be required to obtain one neutron per second per gramme of deuterium. If the deuterium were a gas with a concentration of about 10^{23} atoms per cm.^{3} a temperature of about 5.10^5 degrees would be required to produce a measurable effect in a gramme of deuterium. The gas would occupy a volume of 30,000 m.^{3}.

Thus, even to approach the threshold for production of thermo-nuclear processes the temperature of matter must be raised to a very high level. At such temperatures and under stationary conditions the deuterium should be an almost totally ionized plasma.

The amount of energy which must be concentrated in the plasma to raise its temperature to a level sufficient for the production of intense thermo-nuclear reactions should be comparatively small. Thus, the amount of thermal energy necessary to raise the temperature of one gramme of deuterium to 10^6 degrees equals only a few kilowatt-hours.

Therefore, if one were able to invent a method of heating the plasma with practically no thermal losses, even a low power energy source could be used to induce intense thermo-nuclear processes. The main problem is to exclude heat losses, which rapidly increase with the temperature, since the thermal conductivity of the plasma is proportional to $T^{5/2}$.

When matter is heated to a temperature of only several tens of thousand degrees the losses in the absence of thermal insulation will be so great that further increase of temperature will be practically impossible.

There is another obstacle which arises when dense substances are heated: one must overcome the enormous mechanical forces which result from increase of the pressure with temperature. On heating initially solid or liquid deuterium we find that already at $T=10^5$ degrees the pressure exceeds a million atmospheres. Therefore, thermo-nuclear reactions can be induced only during a very short period of time in dense substances, and such a process will always resemble an explosion (which, however, may not be dangerous) or a brief pulse.

On considering the various ways of generating intense controllable thermo-nuclear processes one finds that there are quite a number of directions which may be followed in attempting to solve this problem.

On the one hand there are the approaches which lead to stationary thermo-nuclear reactions, and on the other those which are based on the idea of utilizing an instantaneous temperature rise in

transient processes of very brief duration. However, irrespective of the way the investigation is carried out, there is one problem that is inevitably encountered, namely, the isolation of the plasma heated to a high temperature from the walls of the vessel in which it is confined. In other words, a means must be found to keep the fast particles within the plasma over a period sufficient for the particles to have a good chance to react with each other.

Magnetic Thermal Insulation

One of the ideas proposed in connection with this problem was that of using a magnetic field for thermal insulation of the plasma. Academician Sakharov and Academician Tamm were the first to point out this possibility in 1950. In a sufficiently strong magnetic field electrons and ions can freely move only along the lines of force. In a plane normal to the lines of force the particles will move along circles of small radius. The positions of the centres of these circles can vary only as a result of collisions, each collision displacing the centre by a distance of the same order of magnitude as the radius of curvature of the particle trajectory. If the radius of curvature of the trajectory is small compared to the mean free path, diffusion of the particles and thermal conductivity of the plasma in the plane normal to the magnetic field will be greatly diminished. The theory of processes taking place in completely ionized plasma indicates that at high field strengths H and high temperatures the transverse thermal conductivity coefficient is inversely proportional to H^2 and decreases by many orders of magnitude with respect to the value found in the absence of a magnetic field. Under these conditions, however, radiation losses must be taken into account.

The magnetic field required to provide the thermal insulation may be produced by passing a sufficiently intense current through the plasma. The current will also heat the plasma as a result of Joule losses and of the work of electrodynamic forces. These considerations were the basis for carrying out theoretical and experimental studies of the physical processes which occur in a plasma on passage of intense currents.

Theoretical Considerations

We shall first examine the principal theoretical concepts which preceded the experimental work. When a current is passed through a plasma the latter should contract under the action of electrodynamic forces (attraction of parallel currents). An increase of plasma temperature should follow. If a contracted column of the plasma is detached from the vessel wall as a result of electrodynamic contraction ("pinch" effect), its temperature may be estimated from the condition that the pressure of the ionized gas is balanced by the electrodynamic forces. A simple computation shows that in such quasi-stationary contraction processes the plasma temperature should be proportional to the square of the current. As is well known, if the electrons and ions are in thermal equilibrium the plasma temperature can be expressed by the equation:

$$T=\frac{I^2}{4Nk}$$

Here I is the current expressed in electromagnetic units, N is the number of particles of a given sign per centimetre length of discharge tube and k is the Boltzmann constant. Investigation of the conditions of thermal equilibrium showed that for $N\sim10^{17}$ the electron and ion temperature should be practically identical. At appreciably lower values of N only the electron temperature will increase.

A contracted plasma column detached from the walls can exist only as long as the current is building up. If the current is constant the column will disintegrate and come into contact with the walls.

It is evident that a thermo-nuclear reaction with a constant yield over an appreciable period of time cannot be produced by passing a current through a plasma. In principle it should be feasible to periodically heat the plasma and induce thermo-nuclear reactions in phase with the peak current. Calculations of the expected thermo-nuclear effect led to the following result, which at first glance may seem paradoxical. It was found that during a single heating cycle the total number of elementary nuclear interaction acts pertaining to a given value of the peak current should be independent of the duration of this cycle. Thus, it seemed that it should be possible to excite very intense thermo-nuclear reactions by sending pulsed discharges of very short duration through deuterium on the condition that the current was sufficiently large. Theoretical calculations indicated that already a current of 300,000 amp. should be sufficient to produce an appreciable emission of neutrons of thermo-nuclear origin. At currents of several million ampères the emission should be very intense. Such were the theoretical predictions which preceded the experimental work.

Powerful Pulsed Discharges

Further development of the conceptions regarding the nature of the processes occurring in a plasma during the passage of an intense current was profoundly influenced by the new facts discovered during experimental investigation of powerful pulsed discharges. These results completely altered the landscape and colours of the picture created by the first spurts of theoretical effort.

Experimental investigation of intense pulsed discharges was carried out over a broad range of the parameters characterizing the initial discharge conditions.*

Discharges through hydrogen, deuterium, helium, argon, xenon and gas mixtures (deuterium-helium, deuterium-argon, deuterium-xenon) of various relative content were studied. The measurements were carried out at gas pressures ranging from 0.005 mm. Hg to one atmosphere. Most of the experiments were performed with straight discharge tubes. The length of the discharge gap varied from several centimetres up to two meters and the diameter from 5 cm. to 60 cm. The discharge was produced by a voltage of several tens of kilovolts. The peak current varied from 100,000 amp. up to 2,000,000 ampères, the rate of build-up of the current lying between 10^{10} amp./sec. and 10^{12} amp./sec. The maximum instantaneous power released in the plasma in these experiments attained as much as 40,000,000 kilowatts.

Banks of high voltage condensers were used to produce the discharges. The leads which carried the current from the condenser to the discharge gap were designed in such a manner as to keep the parasitic inductance of the electric circuit down to minimum, since this factor restricted the magnitude of the current and its rate of growth. For a voltage of 50 kV and total capacity of the condenser bank of several hundred μF the parasitic inductance of the circuit and switch was only 0.02-0.03 microhenry (in those cases when the current growth was maximal).

Oscillograph Records

Oscillographic methods of measurement of the main parameters characterizing the state of the plasma during passage of a current were developed and these were used to study the intense pulsed discharges. Oscillograph ultra-high-speed moving picture cameras (up to 2,000,000 frames per second) were used as well as photography by aid of Kerr cells supplied with special electroexplosive types of shutters.

In addition to the discharge current and voltage, oscillograph records were also made of the intensity of separate spectral lines from the plasma, of the neutron and X-ray intensity, of the magnitude of pressure pulses measured with aid of piezo-electric elements and also of the instantaneous magnitude of the magnetic and electric field strengths at various points within the plasma. The magnetic and electric fields were measured with small probes in the form of miniature coils, loops or needle electrodes of various shape which could be placed at various points within the discharge vessel.

Of greatest interest is the first phase of the discharge during which the plasma current rises from zero to the peak value. On the experiments discussed here this phase lasted from 3 to 30 micro-seconds. At the beginning of the discharge after breakdown of the gas a smooth increase of the current and voltage in the discharge gap takes place. After a certain period of time a sharp decrease of the voltage occurs. At the same time a more or less pronounced kink can be seen on the current oscillogram (see Fig. 1 which illustrates the general nature of time variation of the current and voltage). After the first drop the voltage began to increase rapidly and then sharply dropped again. This second voltage decrease was paralleled by appearance of a new kink on the current oscillogram. In some cases three consecutive sharp changes in the otherwise smooth variation of the current and voltage was observed at the first stage of the discharge.

These characteristic features of high current pulsed discharges are especially

* In England pulsed discharges in gases have recently been investigated by I. D. Kraggs and his collaborators, S. W. Cousins and A. A. Ware, and others.

pronounced when the discharge takes place in gases of low atomic weight (hydrogen, deuterium, helium) and at low initial pressures.

When the rate of current build-up is of the order of 10^{11} amp./sec. the interval between breakdown of the gas and appearance of the first voltage drop comprises several microseconds.

This time interval is a regular function of the parameters characterizing the initial conditions of the discharge. For a given discharge tube diameter it approximately varies as the fourth root of the gas mass per centimetre length of the discharge gap.

The inductive resistance is much larger than the ohmic one in pulsed discharges in which the current increases at a high rate. Thus, by using current and voltage oscillograms one may find the time dependence of the inductance of the plasma column and hence determine how the radius of the column changes at various stages of the process. An analysis of this type indicates that in all cases the very first stage of the process featured by an increase of the inductance due to contraction of the plasma towards the discharge tube axis. The speed of constriction of the plasma increases with the initial current build-up rate (that is, with the derivative dI/dt and decreases with the gas density. At the moment when the kink on the current oscillogram appears and a sharp drop in the potential is observed the inductance begins to decrease. This means that this moment corresponds to maximum contraction of the plasma filament. This situation is followed by a rapid expansion of the plasma filament. The appearance of several kinks on the current oscillogram signifies that consecutive contractions and expansions of the column take place.

These conclusions which were obtained by analysing current and voltage oscillograms are confirmed by data obtained by applying ultra-high-speed cinema photography of pulsed discharges in tubes with transparent walls.

Valuable data on the main physical processes occurring in intense pulsed discharges can be obtained by measuring the magnetic and electric field strengths in plasma. Magnetic field measurements permit one to draw the following picture of current distribution in the plasma. Directly after breakdown the current conducting region is a thin cylindrical layer adjacent to the discharge tube walls. The inner boundary of this layer, at first slowly and then more rapidly, moves towards the axis. After a certain interval of time the current fills the whole tube as a result of movement of the inner current boundary. The moment at which the current reaches the axis practically coincides with the time of appearance of the first kink on the oscillogram.

The current density near the discharge axis at this time exceeds the mean current density over the cross-section of the tube by several dozens of times. On subsequent expansions and constrictions the current density remains very high in a central region of several centimetres in diameter, although appreciable fluctuations are observed.

Current Density Discharge

The current density distribution over the cross-section of the discharge tube at various periods of time is schematically shown in Fig. 2. The current density distribution at the very first stage of the discharge is shown in the left figure. The second one refers to the moment when the current was moving towards the axis. The distribution after the first contraction of the plasma column is illustrated in the right figure. An interesting feature of this stage of the process is that in a certain zone of the discharge the current reverses its direction.

The velocity of the ionized gas is the quantity which directly characterizes the dynamics of a pulsed discharge.

In a plasma of sufficiently high conductivity this velocity is determined by the ratio between the longitudinal electric field strength E and the magnetic field strength H:

$$v = \frac{cE}{H}$$

Measurements of E and H indicate that in a pulsed discharge with rapid growth of current the radial velocity of the plasma may be very high. In the experiments described here the maximum velocity during contraction and expansion of the plasma column in rarefied gases was found to reach hundreds of kilometres per second. This signifies that the kinetic energy of the drift of the plasma ions is of the order of several hundred electron-volts.

One of the most interesting effects observed in intense pulsed discharge in light gases is the appearance of penetrating radiations. In 1952, soon after experiments with pulsed discharges were started, it was found that at sufficiently high currents the discharge in deuterium becomes a source of neutrons.

Discharge in Deuterium

The first experiments performed with the aim of studying this phenomenon showed that the neutrons appear under conditions when the peak discharge current is 400-500 k-amp. and the initial deuterium pressure is about 0.1 mm. Hg. The neutron emission was observed in a relatively narrow pressure range and its intensity rapidly increased with increase of the applied voltage, that is, with increase of the peak current. In these first experiments the radioactivity induced in a silver target embedded in a paraffin block placed near the discharge tube served as the neutron detector. A possible explanation of this phenomenon was that the neutron emission resulted exclusively from collisions between the accelerated deuterons and deuterium adsorbed by the electrodes on tube walls; control experiments, however, did not confirm this explanation.

At the early stages of investigation it was quite natural to assume that the neutrons resulted from thermo-nuclear reactions in the plasma heated to a high temperature. This was exactly what was expected from the beginning and the fact that the effect was detected under conditions which completely corresponded to the *a priori* theoretical predictions seemed to speak in favour of this viewpoint. The behaviour of the neutron radiation (its dependence on pressure and current) observed in the first experiments qualitatively

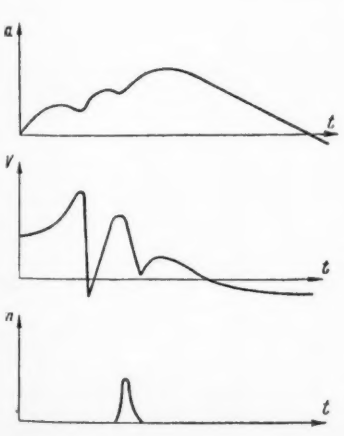


Fig. 1. Current oscillogram illustrating the general nature of time variation of the current and voltage.

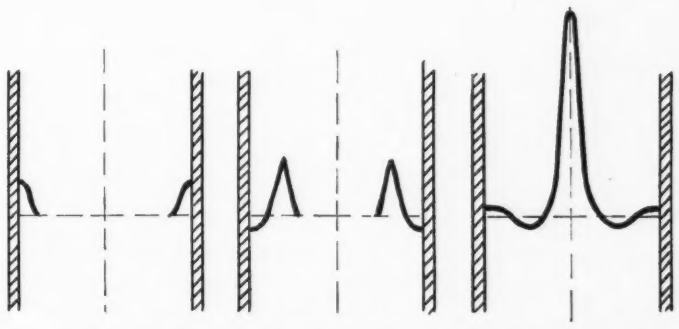


Fig. 2. Current density distribution over the cross-section of the discharge tube. (Left to right): first stage of discharge; moment when the current is moving towards the axis; distribution after the first contraction of the plasma column.

concorded with the assumption that the phenomenon was due to thermo-nuclear mechanism. However, very soon serious doubt concerning the correctness of this assumption began to appear. This happened after it was found that neutrons can be observed at comparatively small discharge currents, of the order of 150,000 amp. According to the initial calculations the intensity of the thermo-nuclear reaction at currents of 150,000 amp. should practically be zero.

In subsequent experiments the neutrons were recorded with a scintillation counter feeding an oscillograph. This technique made it possible to find the relation between the discharge properties and the moment of appearance of neutrons. It was found that the neutrons were always emitted when the second kink appeared on the current oscillogram, that is, at the moment when the plasma was subjected to the second contraction. No neutrons were produced during the first contraction. The neutrons were always emitted as short pulses with a steep front. The rise time of the pulses was several tens of micro-seconds. The chief results of the oscillographic investigations were not consistent with the initial assumption that the neutron emission is the result of quasi-stationary heating of the plasma during which the temperature increases proportionally to the square of the current.

Plasma Neutron Radiation

Further investigation yielded new interesting facts pertaining to the plasma neutron radiation. It was established, in particular, that in specially designed discharge tubes the neutrons could appear at fairly high deuterium densities, as much as several tens of millimetres of initial pressure. This fact signified that the neutron emission was certainly not a trivial effect.

It was found that not only neutrons but hard X-rays as well were produced in pulsed discharges. Penetrating X-rays were found when large currents were passed through hydrogen, deuterium and helium. The radiation produced by discharges in deuterium always consisted of short spurts. The pulses due to the neutrons and X-ray quanta always appeared simultaneously on the oscillograms. The energy of the X-ray quanta produced in pulsed electrical processes in hydrogen and deuterium reached 300-400 keV. It is noteworthy that at the time of emission of such high energy quanta the voltage applied to the discharge tube was only about 10 kV.

Theoretical analysis of the complex phenomena which occur in the plasma of a pulsed discharge oscillating under the action of electrodynamic forces is still at such a stage that quite a number of facts remain to be explained. However, the general picture of the process is gradually becoming clear and some of the peculiarities of the phenomenon seem to have been sufficiently elucidated.

It is now clear that contraction and expansion of the plasma are not quasi-stationary processes characterized by equilibrium between the external and internal pressures.

In the equations describing the dynamic of a pulsed discharge the main term is that which accounts for momentum changes in the ionized gas due to magnetic pressure. The kinetic energy of the ordered motion should at some stages of the process, therefore, greatly exceed the thermal energy concentrated in the plasma.

At the initial stage of the discharge the internal pressure in the plasma is very small and the electrodynamic forces, therefore, produce acceleration along the radius towards the discharge tube axis. Thus, the work of the electrodynamic forces is not expended in raising the temperature but in imparting kinetic energy to the converging plasma layer. At this stage the discharge tube operates as a peculiar type of accelerator in which the particles are driven by the magnetic field. Since charged particles, irrespective of sign, will move with the same velocity, the kinetic energy acquired by the ions will be quite large, whereas the kinetic energy of the electrons practically will not change in virtue of the small mass of these particles. From the viewpoint of gas dynamics the contraction process should be considered as a phenomenon in which a cylindrical shock wave converging towards the axis is produced in the plasma. At first, the gas located before the inner wave front is not ionized. When the wave begins to move the gas is carried along together with the charged particles of the plasma, and its atoms simultaneously become ionized. The amount of matter which begins to move gradually increases and the total amount of ions and electrons in the plasma rapidly increases. The duration of the contraction phase can be determined by calculating the velocity acquired by the contracting gas. It was found to be approximately proportional to

$$\sqrt{\frac{M}{V_0^2}}$$

where M is the mass of gas per unit length of discharge tube and V_0 is the initial voltage. This is exactly what one finds experimentally for the interval between breakdown and appearance of the first kink in the current oscillogram.

Temperature during Maximum Contraction

The final stage of cumulative contraction sets in when the plasma accelerated by the magnetic field reaches the axis. At this moment a great part of the energy of ordered motion changes into heat and the pressure and plasma temperature sharply increases. During maximum contraction the plasma temperature may be of the order of 1,000,000 degrees. The nature of the processes occurring during maximum contraction are not very clear, but apparently after maximum cumulation a diverging shock wave should appear which drives the plasma towards the walls. Inside the outgoing wave there should be a rarefied zone. Under the action of electrodynamic forces which tend to compress the current the outgoing wave should be abruptly decelerated and a new phase of contraction should ensue. This stage differs from the first in that the density in the inner region of the discharge is small and the gas in this region is probably almost completely ionized. As a result, during the second contraction conditions are produced which are favourable fo acceleration in the longitudinal electri field a certain group of ions and electron located near the discharge axis, that is, i the region in which the magnetic field small. One may note here a certai analogy with the accelerating mechanism proposed by Fermi in his theory of origi of cosmic rays. A plasma of high con ductivity will move together with its mag netic field, and with respect to particle located in the inner zone it will be equiva lent to a converging magnetic wall fro which the enclosed electrons and ions wi repeatedly be reflected, their energy in creasing after each reflection. Accelera tion of ions and electrons in the longi tudinal electrical field near the discharg axis is possibly the explanation of appear ance of neutrons and penetrating X-rays The electric field strength during th second contraction may be very high. I may exceed the instantaneous externa voltage applied to the discharge tube b many times.

Acceleration of Ions

However, it must be mentioned that no all in this acceleration mechanism is ye clear. Under certain conditions acceler tion of ions in a longitudinal electric fiel may also be possible outside the centra zone of the discharge, due to the presenc of space charges. Some types of in stability which are peculiar of the colum may play an important role in acceleratin particles in the plasma. In particular, on type of instability observed experimentall may be of importance in the acceleratio of electrons. It consists of the spon taneous creation of a longitudinal magnet field in the plasma as a result of spirallin of the plasma column.

If the second contraction is followed b a few more oscillations of the plasm column the acceleration of the particle may be repeated several times. Experi mentally not more than three successiv oscillations have been observed. A pos sible explanation of this is that the plasm may begin to interact with the discharg tube walls, with the result that the wa material begins to evaporate and appre ciable amounts of foreign gases appear i the volume.

Conclusions

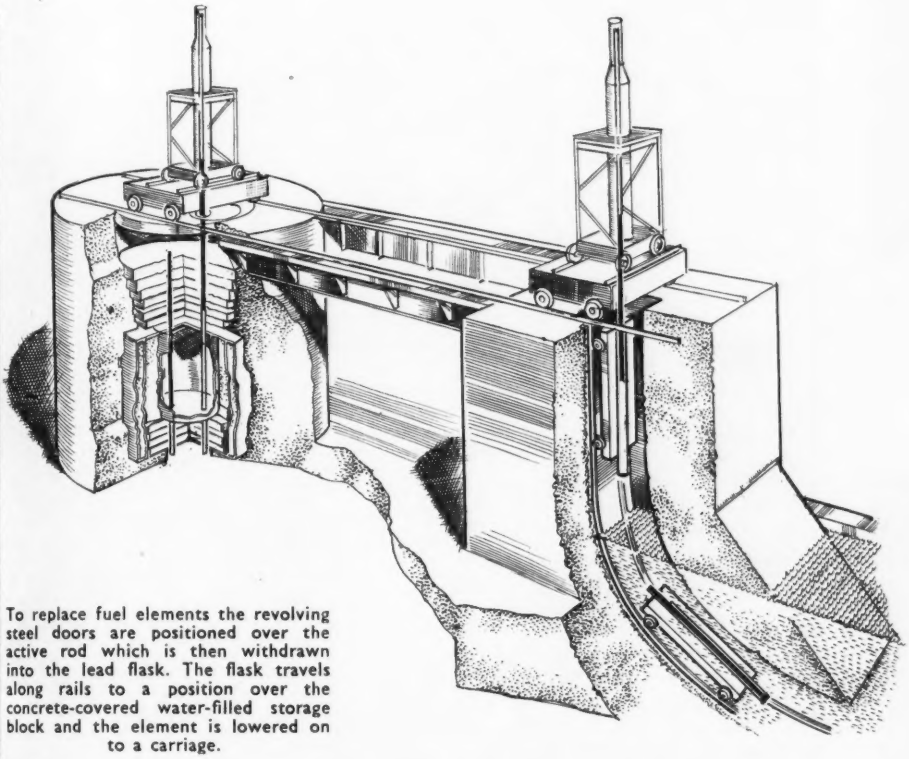
We considered here some features o the phenomena which accompany th passage of intense pulsed discharge through rarefied gases. The success o further work in this direction will greatl depend on the possibility of creating con ditions under which the plasma colum will experience multiple oscillations dur ing build-up of the current without com ing into contact with the walls. However there are serious reasons to believe tha this cannot be achieved.

On appraising the various approache to the problem of obtaining intens thermo-nuclear reactions we do not deem it possible to completely exclude further attempts to attain this goal by using pulse discharges. However, other possibilitie must also be carefully considered. Espe cially interesting are those in which th idea of stationary processes may be used

The World's Reactors

No. 3 — N R X

(Right) Cross section of NRX. Left of C.L. is in the direction N-S through the thermal column and right of the C.L. is in the E-W direction.

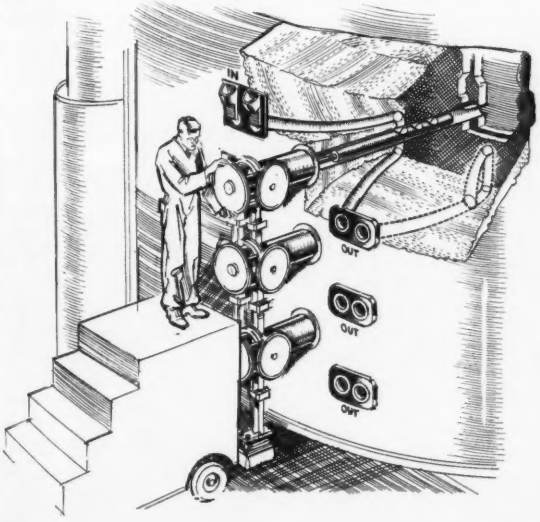


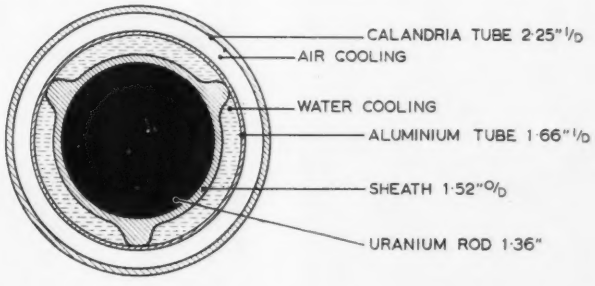
To replace fuel elements the revolving steel doors are positioned over the active rod which is then withdrawn into the lead flask. The flask travels along rails to a position over the concrete-covered water-filled storage block and the element is lowered on to a carriage.

KEY

1. Lead door
2. Lead door hoist
3. Thermo-couple holes
4. Calandria
5. Top calandria tube plate
6. Bottom calandria tube plate
7. Calandria extension bellows
8. Thermal column
9. Air inlet
10. Air exhaust
11. Drain to sump
12. Cadmium shutter
13. Ion chamber cavity
14. Gusset plate
15. Revolving steel doors
16. Conversion rods
17. Ring cooling header
18. Shut off rod
19. Pneumatic gun
20. Coolant inlet valves
21. Fuel rod
22. Experimental hole
23. Coolant outlet valves
24. Control rod
25. Air circulating fan
26. Outlet header
27. Water filled shields
28. Heavy water level
29. Helium filled

Samples for irradiation are placed in an aluminium ball which runs down the continuously dropping and curving channel into the graphite plug which can then be moved into the pile. On withdrawal the rod is turned to allow the ball to roll out and down a similar channel into a shielded container.





Cross section of NRX fuel rod assembly. Immediately surrounding the sheathed uranium is an annular space through which river water flows. The fuel rod sits symmetrically in the calandria tube and air is forced through the annular gap.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Ackno

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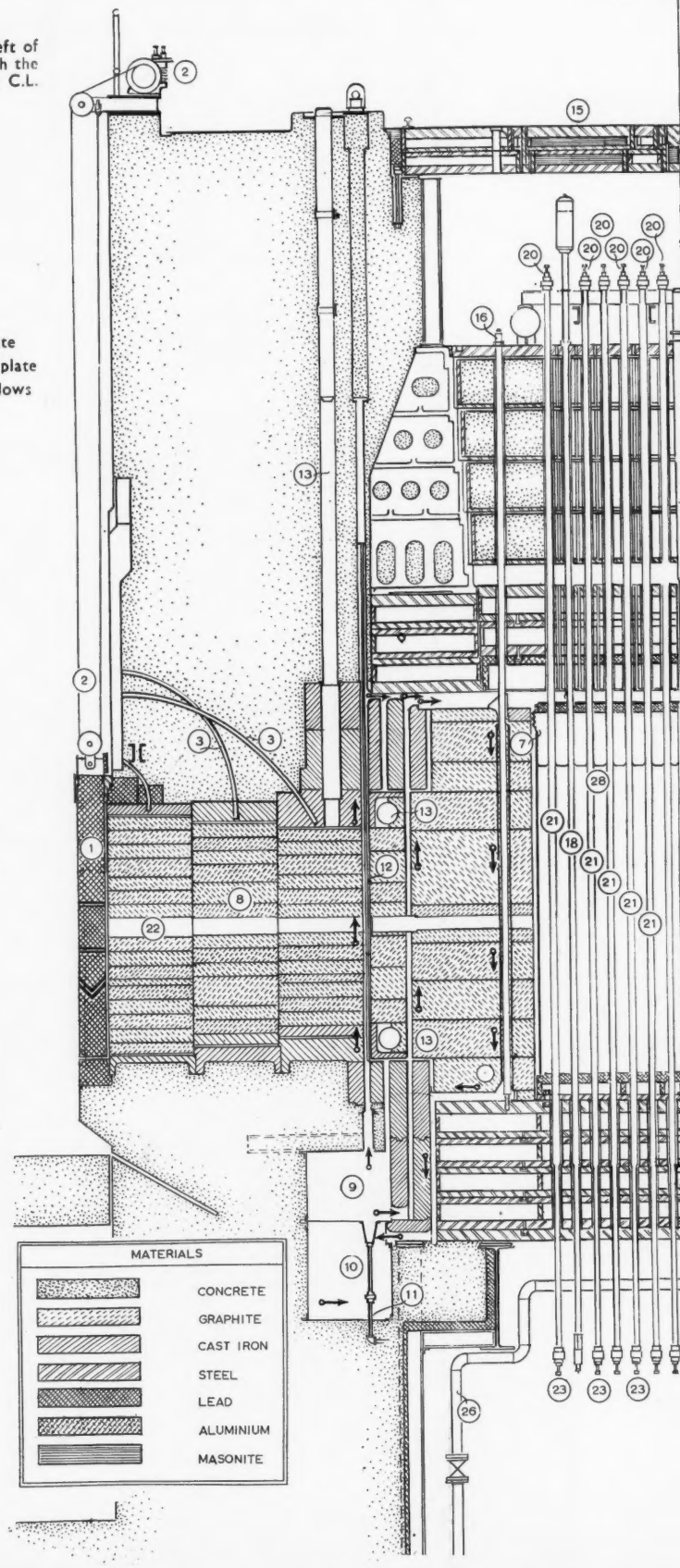

LANDRIA TUBE 2·25" I/D
NG

OLING
LUMINIUM TUBE 1·66" I/D

EATH 1·52" O/D

RANIUM ROD 1·36"

mediately surrounding
ough which river water
calandria tube and air
r gap.

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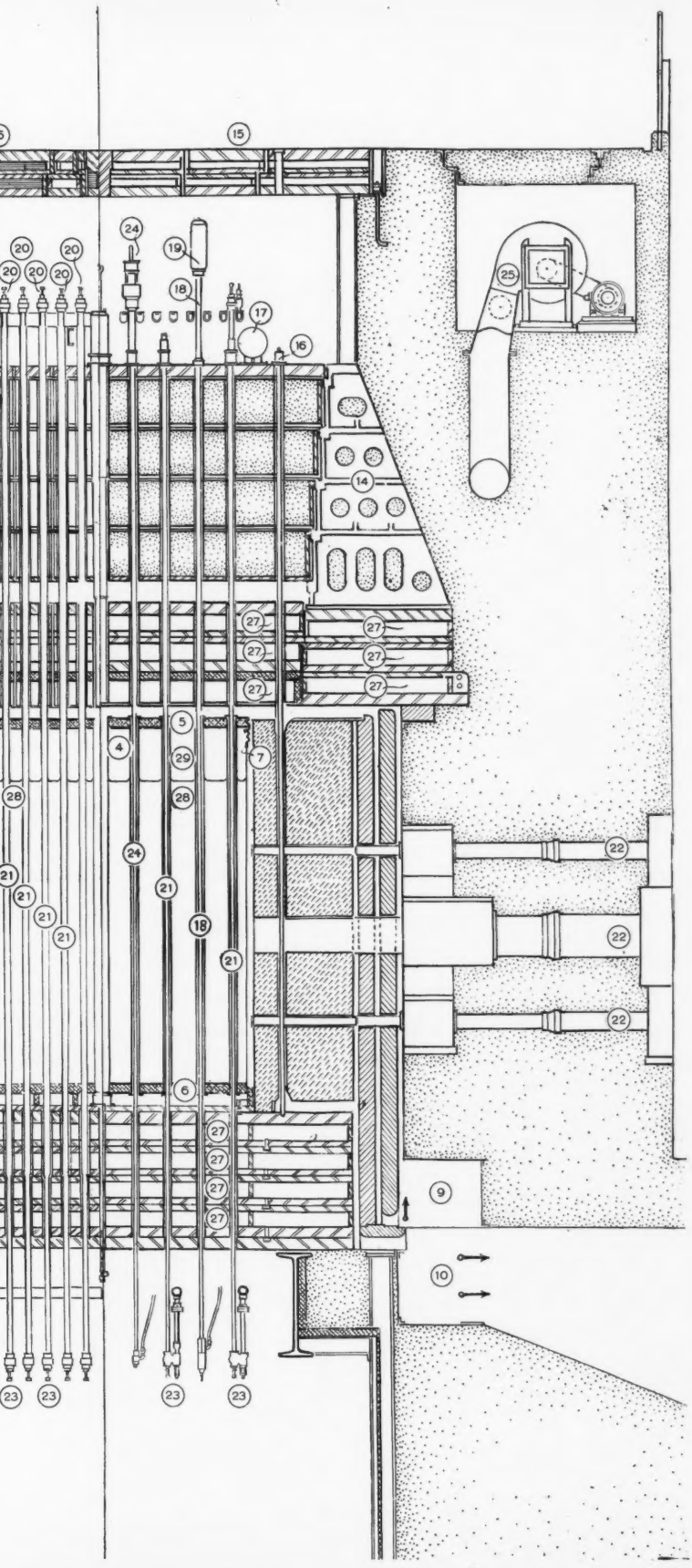
and postage only*

Acknowledgment is due to Atomic Energy of Canada Ltd. for supplying the d
Nuclear Engineering,



ying the drawings upon which these illustrations, drawn by a staff artist of *Engineering*, are based.

The World's Reactors No. 3

N R X — NATIONAL RESEARCH EXPERIM

TYPE:	Thermal heterogeneous.
PURPOSE:	General research using pile radiations. Production of radio-isotopes. Production of U^{233} from thorium; production of Special test loops.
LOCATION:	Chalk River, Canada, 130 miles from Ottawa.
OPERATION:	Commenced operation July 22, 1947.
FUEL:	Natural uranium. Rolled metal bars, 1.36 in. dia. x 10.25 ft. long. Charge for operation: 10.5 tons. Maximum fuel temperature:
FUEL CANS:	Pure aluminium (U.S. spec. 1S). Wall thickness: 0.080 inch. Can temperature:
FERTILE:	Thorium (as oxycarbonate). Form: Rods, $2\frac{1}{8}$ in. diameter, made of pellets. Number of rods: 90 at 4-in. separation.
MODERATOR:	Heavy water. Weight of D_2O: 18 tons approx. Max. temperature: 50°C.
CORE:	Reacting core: cylinder of heavy water 8.75 ft. dia Height of D_2O for criticality about 7.2 ft. Lattice: Regular equilateral triangular lattice $6\frac{13}{16}$ Number of fuel channels: 175 (199 channels in 2 available).
REFLECTOR:	Graphite. Inner: 9-in. layer of graphite next to calandria. Outer: 24-in. layer of graphite. Air gap: $2\frac{1}{2}$-in. air-gap between inner and ou accommodate uranium rods and air cooling.
LATTICE CONSTANTS:	Thermal utilization factor—(f). Fast fission factor—(ϵ). Neutrons born per neutron absorbed in fuel—(η) Resonance escapes probability—(p)= (Slowing-down length)^2—(L_s^2)=114 cm^2. (Diffusion length—(L_d^2)=156 cm^2. Critical buckling—$B^2=4.07 \times 10^{-4}$ cm^{-2}.
COOLANT:	Fuel cooling: light water from Ottawa River. Flow rate: 3,500 gallons per minute. Temperature rise: 40°C. Outlet water: returned to river after 2 hours ho Shielding and thorium blanket cooling: Air, 70,000 Moderator cooling: River water in external heat 250 gallons per minute. Air in calandria fuel
PUMPING POWER:	Normal operating power: 40 MW approx.
FLUX:	Maximum thermal neutron flux: 6.8×10^{13} n/cm^2-s
CONVERSION:	U^{238} to Pu^{239}. Conversion factor: approx. 0.80.
BURN-UP:	Up to 3,000 MW-days per tonne have been repor
CONTROL:	Shut-off rods: 6 in number. Construction: boron-carbide powder in steel tubes Coarse control: height of D_2O controlled by wei Fine control rod: 1 in number. Construction: cadmium slugs in steel tube.
SHIELDING:	Top shields: Inner: Aluminium water cooled. Intermediate: Steel, water-coolcd, Outer: Concrete, four in number, Bottom shields: Inner: Steel and water sandwich, Outer: Steel, four in number, wa Side shields: Inner: Cast iron, 6 in. thick, two between, total weight 155 tons. Outer: Concrete, 7 ft.
OVERALL SIZE:	Diameter: 34 ft. Height: 34 ft.

Figures absent from specification will be published when available

No. 3
XPERIMENTAL

oduction of Pu.

Ottawa.

5 ft. long.

pellets.
n.

8.75 ft. dia. x 10.5 ft. high.
ft.
lattice $6\frac{13}{16}$ in. pitch.
hannels in 22 hexagonal rings

calandria.

ner and outer reflectors to
cooling.

in fuel—(η)=2.112 (U^{235}).

n^2.

$^{-2}$.

River.

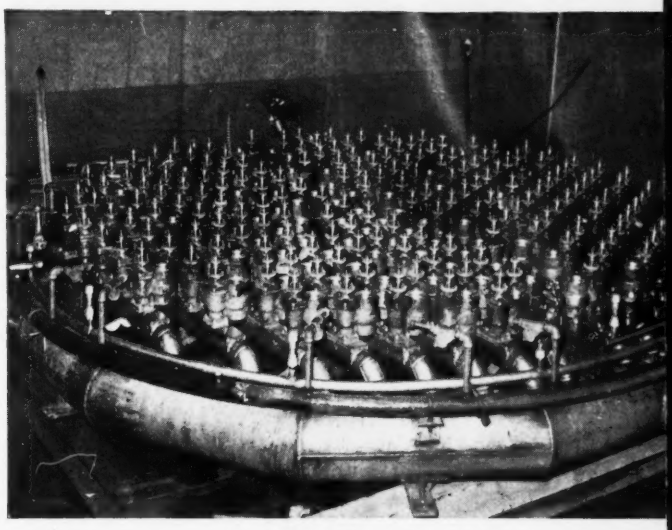
2 hours hold-up.
Air, 70,000 lb./hr.
ternal heat exchanger,
andria fuel channels.
ox.
10^{13} n/cm^2-sec.

been reported.

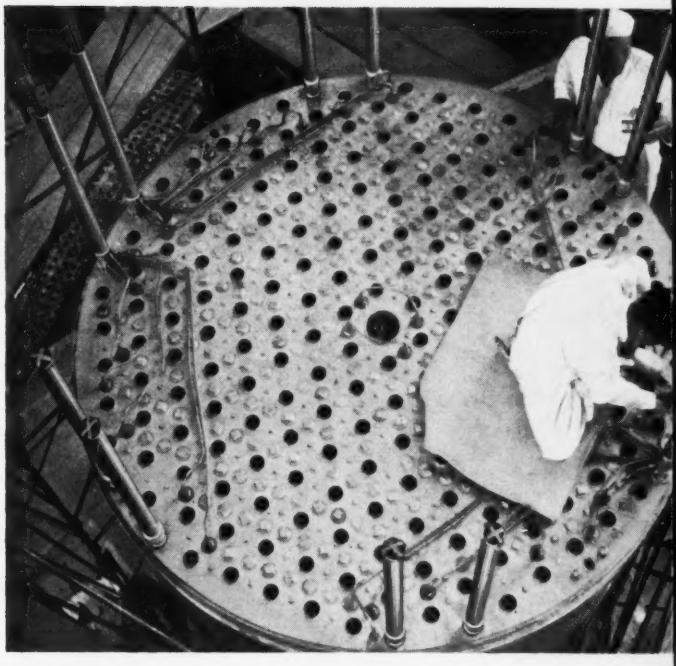
steel tubes.
lled by weir.

ube.
er cooled.
ater-cooled, two 5 tons each.
in number, 17 to 19 tons each.
sandwich, water cooled.
number, water cooled.
thick, two layers, air cooling
155 tons.

en available.

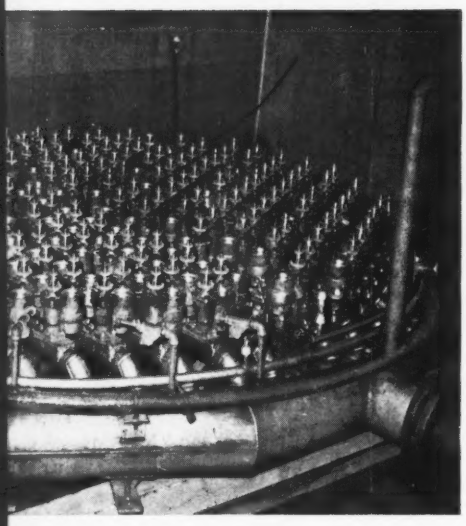


View of the top of the reactor immediately below the rotating shield,
cooling connections to the fuel rods—cooling water ring header in fo

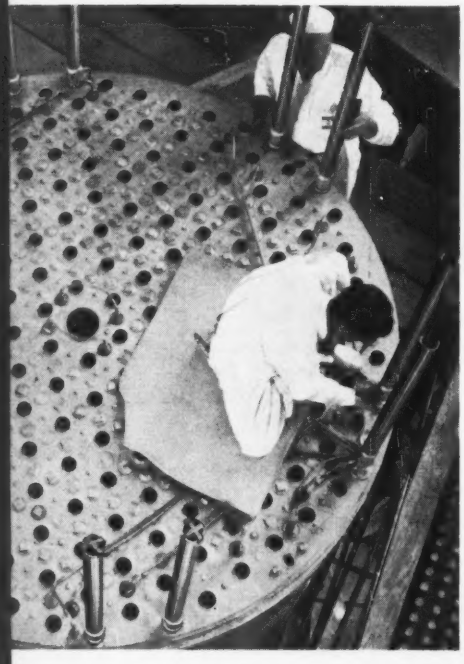


Above—Looking down on the top cover plate of the calandria showing the h
lattice of fuel element tubes and the central experimental hole. Shut-off an
rods occupy vacant fuel channels. Details of cooling and scavenging are
available.

Right—Lower ends of fuel rod assemblies and shut
This photograph was taken during the reconstructio
tions following the power surge on December 1
hence mask and protective clothing.



r immediately below the rotating shield, showing
l rods—cooling water ring header in foreground.



cover plate of the calandria showing the hexagonal
the central experimental hole. Shut-off and control
s. Details of cooling and scavenging are not yet
available.

ver ends of fuel rod assemblies and shut off rods.
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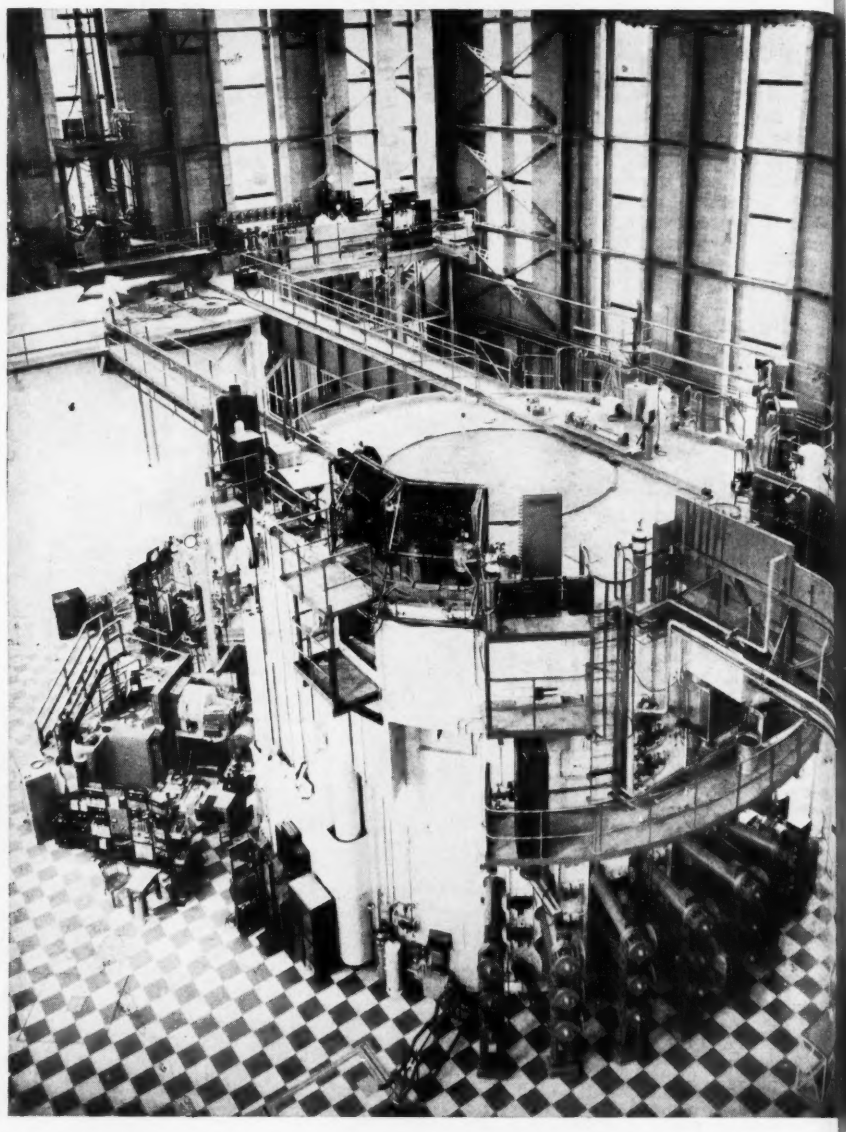
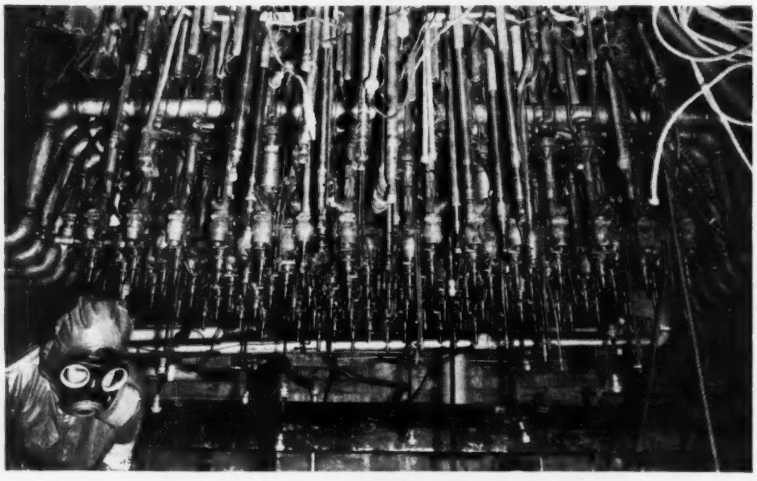
wing the power surge on December 12, 1952—
hence mask and protective clothing.



General view of NRX. The rod emerging from the top shield is an extension of the single contr
rod. In the right foreground can be seen a bank of self-serve mechanisms for sample irradiatio
and top left the lead flask in position over the storage block.



Radiological Protection on Trial

Radiation protection practice must be developed with its economics in mind. The nature of the dangers is discussed under the headings of external and internal hazards followed by an examination of the meaning of the term "permissible" in relation to the m.p.l.

by
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MANY of the principles of radiological protection were recognized, if not well-defined, prior to the era of atomic energy so that the growth of experience in radiation work has led to a process of refinement rather than to the enunciation of a completely new set of principles. There has been a growing sense of perspective, particularly in the management of radiation work; by comparison, the evolution of an attitude to safety through design has been less conspicuous and more subtle. It is still true, however, that successful radiation protection must be founded upon the application of sound principles in the planning and design of atomic energy installations and it is greatly to the credit of all who have been concerned with nuclear energy development that so many of the principles that were adopted in the articles of association of the industry have stood the test of a decade of intensive radiation work. Today, it is axiomatic that industrial hygiene is born on the drawing board, yet the atomic energy industry was probably the first major industry to recognize this fact and, by its example, it has made a major contribution to modern occupational health and safety.

However, the industry is presently confronted with a situation which allows no room for complacency; indeed, the need to analyse and to profit from experience is becoming increasingly obvious. In view of the fact that the majority of the safety techniques available to the design engineer are costly and, in many cases, exceedingly costly, radiation safety is an issue of real importance in the economy of the nuclear power project. It is the objective of all good nuclear engineering to provide, as far as possible, a guarantee of inherent safety by design, yet, unless the recommended safety criteria are stated logically and precisely, such a guarantee can only be given at the expense of extravagant and, possibly, unnecessary investment in the name of safety. Therefore, those whose task it is to evolve a code of radiation protection practice have a very clear responsibility to recognize the many far-reaching repercussions of their recommendations in terms of economy and expediency as well as safety and so to take a thoroughly realistic view of this difficult problem.

The Nature of Radiation Hazards

Fortunately, occupational radiation injury is a thing of the past; indeed, the record of safety which has been achieved by the atomic energy industry is unique. Therefore, practically everything that is known of the effects of radiation on human beings has been derived from studies of the injuries that occurred quite commonly among the early radiation workers. The pattern of these injuries shows that there are two distinct types of radiation hazard.

An external radiation hazard is one in which the whole or a part of the body may be irradiated by a source outside the body. In the history of radioactive disease there are numerous examples of the injuries which have resulted from failure to control this type of hazard. Many of these cases occurred in the early days of hospital radiography, but others have been associated with scientific research, particularly with high-energy radiating equipment. It is in connection with these hazards that the engineer is concerned with biological shielding, remote control methods and the limitation of working time. Among the corresponding problems in health supervision are external radiation measurement (e.g., film-badge monitoring) and blood counting.

An internal radiation hazard is one which admits the possibility of a radioactive substance entering the body by breathing, by swallowing or through a breach in the continuity of the skin. Injury has been produced by this mechanism in many cases.

When internal radiation injury occurs, the organ most likely to be affected is that in which the radioactive substance tends to concentrate by virtue of its chemical properties. Plutonium and radium are examples of substances which have a high affinity for bone and they are classed, therefore, as "bone-seekers." Others follow different metabolic patterns; iodine, for instance, concentrates in the thyroid gland. It is evident that radioactive substances vary greatly in toxicity depending upon

(a) biological factors such as the efficiency of selective concentration in the tissues and the extent of absorption, retention and rejection by the body, and

(b) physical factors such as the type and energy of radioactive emission and the radioactive half-life.

In connection with hazards of this type the designer is concerned with measures to avoid contamination of the atmosphere and of surfaces, including benches, floors, clothing and skin and it is in this context that he has to assess the need to introduce methods of containment and ventilation. Monitoring for contamination of the environment and of biological materials such as urine are corresponding problems in health supervision.

From the point of view of design, the problems presented by external radiation hazards are probably no less complex than those associated with internal hazards. In terms of plant management, however, the latter type of hazard is much the more difficult to control. This is important in that the nuclear power programme has been planned so that the chemical processing facilities will be confined to a special site or sites remote from the power stations. It is unlikely, therefore, that any serious internal radiation problems will arise in the operation of the stations and it follows that the requirements of health supervision will be relatively simple at these sites.

There is much to be learned from the pattern of radiation injury. Most types of injury are extremely serious and, as effective therapy is only occasionally a practical proposition, it follows that radiation protection must be concerned essentially with the prevention of injury.

In many cases there is reasonably accurate knowledge of the doses of radiation that have proved to be injurious and this information has provided an invaluable basis from which to derive the safety criteria to which the industry works today; it can be taken for granted that these criteria err in the direction of safety.

None of these diseases is peculiar to radiation over-exposure and there is no means of distinguishing between these and similar cases arising spontaneously. When it is borne in mind that radiation injury may manifest itself only after a long latent period it is obvious that there is no simple or rapid means of demonstrating the success of a policy of radiation

protection. To this end, it is necessary to resort to statistical methods in order to demonstrate a normal incidence of disease among radiation workers and to supplement this information with accurate measurements of radiation exposure.

One of the most important implications of these facts is that, to a very great extent, they are bound to influence the safety policy of the atomic energy industry for some time to come and this policy must inevitably be a conservative one.

Safety Criteria

Occupational Levels. The International Commission on Radiological Protection has recommended maximum permissible levels for a wide variety of conditions of external and internal radiation exposure.

The basic maximum permissible levels for external radiation exposure is 0.3 rem in any week but it is probable that further restrictions will be applied in due course to doses integrated over longer periods extending to the whole working lifetime. When there is only limited exposure of the body or when radiation of low penetrating power is involved, exposure in excess of this figure may be permissible. In exceptional circumstances, it may be permissible to average exposures over periods of not more than three months, the maximum total dose in this case being 3.9 rem. It is desirable that the design engineer should have some feeling for the biological substance of these recommendations and, indeed, for the climate of current biological opinion because he cannot afford to be disinterested in the possibility of future changes in the safety criteria. At the same time, the designer has every right to ask a number of supplementary questions; for example, he may wish to know whether or not it is permissible to plan to expose any individual regularly at 0.3 rem. a week, or to what extent he can regard certain operations of irregular occurrence but involving relatively high exposure for a short time (e.g., reactor charging and discharging operations) as exceptional, and so plan an uneven pattern of exposure for certain individuals, within a satisfactory average level. Thus far, the biological experts have failed to give clear answers to questions such as these and, although it may make sense to the plant manager, it is cold comfort to the design engineer to be told that his aim should be to restrict exposure to the minimum in all cases, in spite of the fact that there is a maximum *permissible* level. These are burning questions and without reasonable answers to them, the engineer is bound to find himself in difficulties in trying, for example, to develop an attitude to a problem as fundamental as that of biological shield design. It appears, therefore, that radiological safety is still, to some extent out of perspective. It has yet to be accepted that to aim at a far higher standard of safety than is looked for in any other walk of life can be a reasonable ideal only when a disproportionate investment is not called for. So far, there has been little support for the idea that safety should be made to pay.

Maximum permissible levels for internal radiation exposure have been recommended for a long list of radio-isotopes in terms of total body load and concentrations in air and drinking water. A few of the appropriate values are shown in the accompanying table.

A striking feature of many of these values is that they are minute by comparison with the figures appropriate to the more toxic conventional chemicals. In the case of plutonium, for example, the maximum permissible level in air is approximately 1/30,000 μg per cubic metre. At the same time, certain substances are exceptional in this sense, the figure for natural uranium being 300 μg per cubic metre and this substance is therefore less toxic than many chemicals in general use. In almost all cases, the maximum permissible levels for radioactive substances are set in terms of chronic exposure leading to the gradual accumulation of radioactive material within the body. It follows that there is always a very great difference between the maximum permissible level and the dose required to produce acute symptoms and, therefore, that the maximum permissible level need not be adhered to for each cubic centimetre of air or of drinking water. For this reason, a decision is required as to what extent a level of contamination in excess of the maximum permissible may be tolerated and for what period—this is an important question in the planning of unusual maintenance work, for example.

In view of the great variation in the toxic properties of radio-isotopes, the basic approach to chemical plant engineering may vary from conventional chemical practice in the case of, say, natural uranium through a series of stages to absolute enclosure in the case of the more toxic materials such as plutonium and there is great scope for the exercise of the art of engineering in matching the requirements of each particular process with appropriate design principles. In certain quarters this is referred to as "optimization."

Public Health Levels. It is sometimes necesasry to resort to off-site disposal of effluents contaminated with traces of radioactivity and it is necessary, therefore, to observe some suitable code of practice based upon the maximum permissible levels of exposure for the general public. A condition of acceptance for radiation work is a thorough medical examination which is intended not merely to fulfil the normal requirements of a pre-employment examination but, more specifically, to ensure the exclusion of individuals who, as a result of some abnormality, might be unduly sensitive to the effects of exposure to radiation. Thereafter, all radiation workers are subject to regular medical supervision including clinical examinations and special tests of the blood and of other biological materials such as the urine.

In evolving a code of practice for problems in public health it has been considered desirable to apply the maximum permissible levels for occupational exposure reduced by some appropriate factor in order to take note of the fact that specific health supervision is not normally available to the general public, nor are they selected in any way for exposure to radiation. At the present time, a factor of reduction of ten is in common use and this is more than sufficient to provide a thoroughly adequate safeguard as far as individual members of the public are concerned. However, it is no easy matter to attain this degree of protection; the magnitude of the problem is to be seen, for example, in the elaborate and costly facilities that have been required for the storage and treatment of effluents and for environmental monitoring. It is evident that the criteria of safety for public health problems are of no less concern to the industry than the conditions which have been recommended for radiation work.

Apart from the well-being of individual members of the general public a very different and even more controversial

TYPICAL MAXIMUM LEVELS FOR OCCUPATIONAL EXPOSURE (1953)

Isotope	M.p.l. in body μc	Critical Organ	M.p.l. in air μc/cc	M.p.l. in water μc/cc
Pu 239	0.04	Bone, gut	2×10^{-12}	3×10^{-6}
Ra 226	0.1	Bone	8×10^{-12}	4×10^{-8}
U-natural	0.04	Kidney	3×10^{-11}	2×10^{-6}
Sr 90	1	Bone	2×10^{-10}	8×10^{-7}
I 131	0.6	Thyroid	6×10^{-9}	6×10^{-5}
Sr 89	2	Bone	2×10^{-8}	7×10^{-5}
P 32	10	Bone	1×10^{-7}	2×10^{-4}
Na 24	15	Lung, Body	1×10^{-6}	8×10^{-3}
Any fission product (beta-gamma)*			1×10^{-9}	1×10^{-7}
Any mixture of alpha emitters*			5×10^{-12}	1×10^{-7}

* For exposure up to a few months.

La Protection Radiologique à l'Essai

La protection radiologique, fondée sur les pratiques des premiers experimentateurs en matières radioactives est devenue un trait essentiel de l'étude du dessin. A l'avenir, pourtant, une plus grande considération doit être donnée aux économies des précautions de sûreté pour réduire les frais superflus. Dans cet article la nature du danger de radiation est indiquée aussi bien que les problèmes que doit résoudre le dessinateur de l'installation. On rencontre deux sortes de dangers, la première de la radiation externe et la seconde de la radiation interne des substances radioactives ingérées ou inhalées. Les deux sortes exigent également qu'un écran suffisant doive être fourni et que la contamination des surfaces d'appui doive être évitée, mais la deuxième sorte est plus difficile à écarter au point de vue du dessin de l'installation et de la direction. Dans une discussion des tolérances qui ont été prescrites, des chiffres sont donnés pour les niveaux maxima permissibles par semaine et pour une periode de trois mois, avec des observations sur l'attitude que doit adopter le dessinateur relativement à ces chiffres. Les niveaux maxima permissibles sont indiqués pour les divers isotopes radioactifs dans le corps, dans l'air et dans l'eau potable. L'article termine par un bref commentaire sur le danger de radiation et sa relation à la santé publique.

Erprobung der Schutzeinrichtungen gegen schädliche Strahlen

Schutz gegen schädliche Strahlen, der aufgebaut werden muss auf den früheren Erfahrungen der Wissenschaftler, die mit radioaktiven Materialien gearbeitet haben, ist ein grundlegender Punkt bei der Durcharbeitung von Konstruktionen. Allerdings wird man in Zukunft mehr Aufmerksamkeit auf die Wirtschaftlichkeit der Sicherheitsvorkehrungen richten müssen, um unnötige Ausgaben zu reduzieren. In dem vorliegenden Aufsatz wird die Natur des Risikos der Strahlung dargelegt, und ferner werden die Probleme aufgezeigt, die dem Konstruktör eines Werkes aus diesem Risiko heraus erwachsen. Das Risiko ist zweifach einmal das von äusserer Anstrahlung, dann das der Einwirkung der Strahlung von innen durch radioaktive Stoffe, die mit Speisen eingenommen oder eingeatmet worden sind. Beide Arten erfordern, dass ausreichende Abschirmung vorgesehen ist, und dass Verseuchung der Flächen, wo gearbeiten wird, vermieden wird, was jedoch bei der zweiten Art schwierig ist, soweit es die Anlage des Werkes und die Betriebsführung betrifft. Bei der Diskussion der Toleranzen, die zugelassen werden können, werden Zahlen gegeben, einmal für die maximal gestattete Menge in der Woche, dann für eine Periode von drei Monaten, mit Bemerkungen über die Stellung, die der Konstruktör gegenüber diesen Zahlen einnehmen sollte. Es werden maximal gestattete Mengen für verschiedene radioaktive Isotopen im Körper, in der Luft und im Trinkwasser gebracht. Der Aufsatz schliesst mit einer kurzen Besprechung des Strahlungsrisikos und seiner Bedeutung für das öffentliche Gesundheitswesen.

Ensayos del Blindaje Protector Radiológico

La protección radiológica basada en las experiencias de los que trabajaban con materiales radiocativos al principio, se ha vuelto una característica básica en el estudio de diseño. Sin embargo, en el futuro se tendrá que prestar mayor atención al lado económico de las precauciones de seguridad para reducir gastos innecesarios. En este artículo, se discute la naturaleza de los riesgos de la radiación en conjunto con los problemas que enfrentan al diseñador de instalaciones. Se encuentran dos tipos de riesgo, el primero de la radiación externa y el segundo de la radiación interna motivada por la ingestión o inhalación de materiales radioactivos. Ambos tipos exigen que se provea un blindaje protector adecuado y que se evite la contaminación de las superficies de trabajo, pero el segundo tipo presenta mayores dificultades en relación a la disposición de la instalación y a su administración. En una discusión con respecto a las tolerancias que se han establecido, se dan cifras de los máximos niveles permisibles por semana y sobre un periodo de tres meses, con observaciones sobre la actitud a ser adoptada por el diseñador en relación a estas cifras. Se señalan los máximos niveles permisibles para los varios isotopos radioactivos en el cuerpo, en el aire, y en el agua potable. El artículo termina con un breve comentario sobre el riesgo de la radiación y su relación a la salud pública.

problem arises out of the possibility that a large part of the population might be irradiated. This is the genetic aspect, and it has recently attracted a good deal more sensational attention than is justified by the present level of understanding of the subject. It is sufficient for the purposes of this article to note that, for the time being, the criterion of genetic safety must lie in ensuring that any additional radiation load borne by the population as a whole remains small by comparison with the background of natural radiation to which it is constantly subjected.

Conclusion

The atomic energy industry has benefited materially from the advice and recommendations of a number of competent authorities on radiological protection. It appears, however, that the attention of these authorities has been directed in the main at the control of radiation hazards under operational conditions rather than at the problems which arise in the planning and design of atomic energy installations and there is still an apparent tendency to shrink from the idea of planned exposure to radiation. However, the British Government is now committed to an extensive programme of nuclear power development and, in the health and safety issues associated with it, radiological protection has yet to face its greatest challenge.

Atomic Energy Course at Birkenhead Technical College

AN introductory course in atomic energy intended mainly for engineers has been held at Birkenhead Technical College. Of sixteen weeks duration, it has been well attended by electrical, mechanical and consulting engineers from shipping companies, the electrical supply industry and other organizations. The course also attracted a group of insurance officials, who wished to be well informed about the possible risks involved in the new developments.

The first few lectures of the course dealt with nuclear theory, radioactivity, and the properties of alpha, beta and gamma rays.

The principles of fission and of reactor construction were then dealt with at some length, including thermal and fast reactors. This was followed by an account of the chemical and physical processing of fuels and the metallurgical considerations for fuel elements and reactor materials. Several special lectures were then given by members of the staff of the U.K. Atomic Energy Authority, Risley, on the principles of health physics; radiation monitoring; disposal of radioactive wastes; and reactor instrumentation. The production and uses of isotopes were mentioned, and Dr. Chalmers of the Liverpool Radium Institute gave an account of the medical uses of radio-isotopes. A valuable feature of the course was a visit to the Nuclear Physics Department of Liverpool University, with an explanation of the principles of the cyclotron.

The course was under the direction of the Head of the Science Department at the College, Mr. D. G. Cooper, B.Sc., F.R.I.C., A.I.B.P., who gave many of the lectures.

It is intended to repeat the course during 1956/57 in two ways: (1) as a fortnight's full-time course, (2) as a part-time course of about sixteen lectures (one per week). Inquiries are invited for either course by Mr. Cooper at Birkenhead Technical College, Borough Road, Birkenhead.

Power Generation in the North of Scotland

The North of Scotland Hydro-Electric Board is planning the large-scale development of thermal plant to supplement the present predominantly hydro plant to give greater operational flexibility. The plan envisages the building of a more advanced type of reactor than those shortly to be built in England for electricity supply.

by
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Chief Electrical and Mechanical Engineer, North of Scotland Hydro-Electric Board.

THE North of Scotland Hydro-Electric Board is responsible for the generation and supply of electricity in their area in Scotland in the same way as the Central Electricity Authority is in England and Wales and the South of Scotland Electricity Board in their part of Scotland. The Hydro Board's area, which is shown in the accompanying map, comprises about three-quarters of the total area of Scotland and includes many very sparsely populated districts and many large islands and groups of islands.

The larger part of the Board's generating capacity is hydro-electric, but it also operates steam and Diesel-driven generating plant. The Diesel stations are principally on the islands where there are no, or only limited, hydro resources and where the cost of transmission from the mainland has not so far appeared to be economic.

As in other hydro-electric schemes, the best operating results are obtained by co-ordinated operation of the thermal and hydro plants. Not only does this allow flexibility in the design of the hydro stations, but the thermal power is used to balance the variations in hydro output which occur with variations in rainfall. It is not usually an economic proposition to provide sufficient water storage to give complete or nearly complete regulation of output from hydro schemes. Thermal generation, therefore, is a valuable complement to the control of reservoir levels.

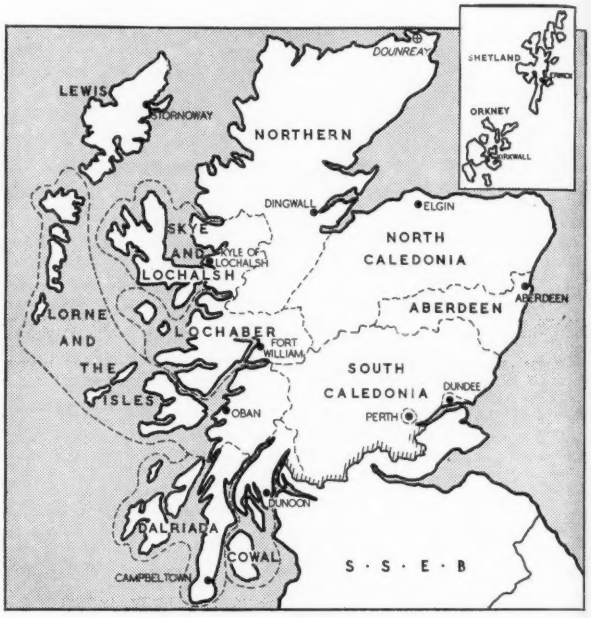
The growth of electricity consumption has been remarkably high over the past five years, averaging 11¼% per annum. This may be compared with the average for the rest of the country of about 8½% during the same period. Apart, therefore, from the considerable amount of new hydro construction now in hand or in contemplation, an extension of steam station capacity is also being carried out with a further amount, possibly oil-burning, to follow at an early date.

Development of additional thermal plant on a larger scale will become necessary in the early 1960's and advance planning assumes nuclear developments for this, operating as base-load plant on the lower part of the load curve. Surveys for suitable sites are in hand and consideration is being given to the most suitable reactor types.

The programme assumes that the first plant will probably be planned in the year 1960 to use a more advanced and improved type of reactor than those at present under construction in Britain for public electricity supply.

It has been generally accepted that nuclear stations will operate at a high load factor and consequently, surplus power may be available at nights and weekends at low incremental cost. This is expected to encourage further the use of off-peak power and will increase its popularity. It also creates conditions favourable for the development of pumped storage schemes for the economical supply of peak load power and, indeed, the Government White Paper of February, 1955, envisaged the development up to 1975 of 2,000-4,000 MW of hydro-electric and pumped storage plants. There are many suitable sites in the Highlands where large outputs up to 2,000 MW in a single scheme could be developed and many of these are quite close to large load consuming areas.

Apart from the projected use in the Board's own area of pumped-storage schemes in association with nuclear plant, active consideration is being given to the development of schemes whose pumping power might be derived from outside the Board's area and whose output might in return go back there.



The North of Scotland Hydro-Electric Board's area includes many sparsely populated districts and numerous islands.

The cost of Diesel generation is high and has made the electricity produced by the Board in some areas by this means particularly uneconomic. Preliminary investigations have been made about the possible use of small nuclear reactors in such areas, particularly some of the larger islands. At present, the indications are that the cost is still rather high for economic development, but the position regarding the development of such reactors is being watched. It is hoped they may become more economic when more enriched fuel is available.

Mention should be made briefly of the United Kingdom Atomic Energy Authority's experimental fast fission reactor project at Dounreay in Caithness. The Hydro Board, by arrangement with the U.K.A.E.A. is providing augmented power supply to the site and co-operating in plans to absorb any export of electrical power which becomes available.

The Board's business will be to construct and operate nuclear power stations whose generation costs are economic in comparison with other methods. They will have the benefit of the technical development and the experience of the U.K.A.E.A. in deciding on technical matters and costs. There is an agreement between the Board and the U.K.A.E.A. dealing with such matters as site selection, design, construction and operation, supply of fuel and other special materials, staff training and exchange of information.

Zirconium

PART 2—Treatment of the Metal

Arc melting techniques have been developed for the melting of the metal with automatic additive feeds for alloy production. Under appropriate conditions zirconium can be forged, rolled, extruded, swaged and drawn into wire or tube. Present world production is reviewed.

by

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REFERENCE has been made in Part I to the absence of a suitable crucible material for molten zirconium and although graphite appeared to be suitable at one time it was found that the small amount of carbon contamination had a very considerable effect in deteriorating the corrosion resistance of the metal. Various methods of melting without contamination were examined and powder metallurgical processes were also explored as a method of consolidation. Some of the melting techniques were interesting, particularly the one suggested by Westinghouse Electric Corporation for "float-melting";[1] that is, heating the metal whilst suspended in space within an electro-magnetic field generated by applying high frequency alternating current to two coaxial coils connected in series opposition. Drip-melting[2] was another method that was proposed; this involved feeding a zirconium bar vertically downwards into an induction coil so that the end was melted and dripped continuously into a copper mould. Most progress in melting zirconium was made at the Bureau of Mines, Albany, Oregon, starting with melting in a graphite crucible in a split-graphite tube resistor furnace and progressing to an arc melting technique operated in a pure argon or helium atmosphere with a water-cooled copper crucible. This technique was developed until small ingots could be produced but these were unsatisfactory as tungsten electrodes were used and the zirconium tended to splash the electrode and cause some tungsten alloy to form and fall into the molten pool. The tungsten electrode also tended to break up when overheated, but for small scale operations where heating of the electrode was limited the results were satisfactory. Following the trouble with tungsten electrodes the next stage in the development was the use of consumable electrodes produced from bars prepared by compacting zirconium sponge (Fig. 1).

The pressed bars were placed around the chamber at the top of the furnace proper and an operator using gloves fitted to the chamber was able to weld the bars together as they were fed down into the arc. The melting took place in argon or, preferably 80% helium and 20% argon; this mixture permitted operating at a higher voltage arc than pure argon and a steadier arc than pure helium.

When this furnace was first used it was considered essential that about 0.02 to 0.04% magnesium should be incorporated in the pressed electrode in order to stabilise the arc. The zirconium sponge was pressed at 50 tons per sq. in. to form electrodes measuring 2 in. by 2 in. by 20 in. and carried up to 5,000 amp. at 40 V when producing 10-in. diameter ingots. Ingots of 200 lb. weight were produced with a power consumption of less than 0.5 kWh/lb.

The production of alloys by arc melting introduced complications because it was not possible to have the whole of the charge molten at one time. As the melting and solidification progressed up the crucible it was necessary to introduce the alloying ingredients at a controlled rate. Although it was found possible to do this with most metals by mixing them with the sponge and pressing together, it was found that it was not possible to obtain homogeneous ingots with low melting point metals, which tended to drain out of the electrode (even as much as several inches above the arc). The last part of the ingot to be formed therefore did not contain any alloying element.

The first alloy required in quantity was Zircalloy and as tin was the principal alloying ingredient it could not be incorporated in the electrode and it was necessary to devise a method of introducing the metal continuously and in proportion to the rate of melting of the zirconium electrode. The speed of melting—several pounds per minute—required that an automatic device should be employed. Several methods were proposed, one of the successful ones was to feed tin wire, at a rate related to the electrode feed, through a die fitted with a cutter so that the wire was cut into small pieces which dropped into the molten pool.

Another device which was successfully employed to produce large quantities of Zircalloy and other alloys, used small tablets of pressed metal powders, about the size and form of an aspirin tablet. This had the advantage that all metals could be added in this form and also all the alloying elements could be introduced together as tablets prepared from the mixed ingredients. The tablets were charged into a spiral vibrating feeder (Fig. 2) which sorted them into single file so that they

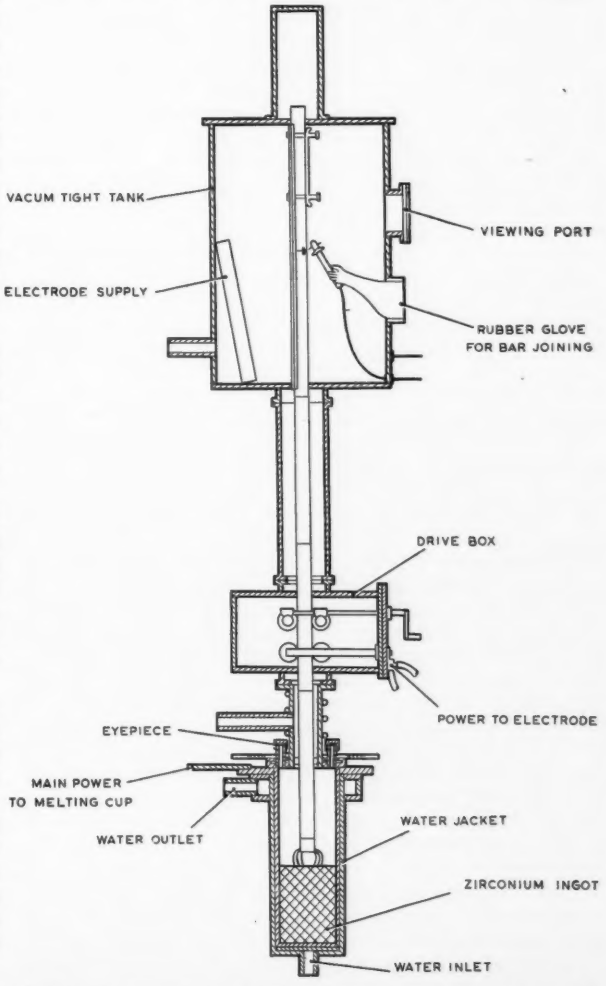

Fig. 1. A consumable electrode furnace developed and used by the U.S. Bureau of Mines.

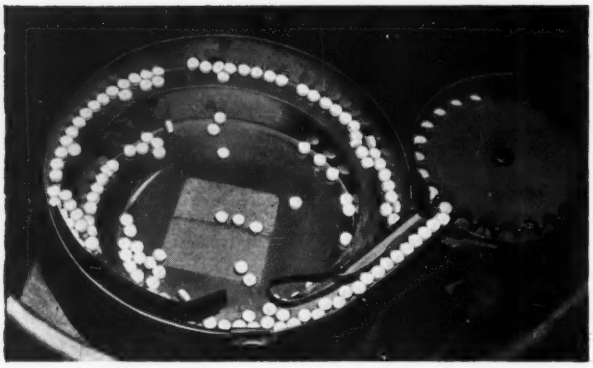

Fig. 2. Pressed metal powder tablets used in making zirconium alloys being sorted and fed into a metering device connected with the electrode feed: this ensures that the correct ratio of alloying elements is maintained.

could be fed to the metering device, which was connected with the electrode feed and ensured that the correct ratio of alloying elements to zirconium melted was maintained.

Despite the success of the automatic feeding device it was found that the results were still not entirely satisfactory. Some of the trouble was caused by the fact that occasionally an alloying tablet dropped to the bottom of the molten pool and became trapped in the cooling metal before there was time for it to melt and disperse. At this stage the Bureau of Mines at Albany, Oregon, introduced a novel method for improving the homogeneity of the ingots. They employed a magnetic field for mixing and obtained this by passing direct current through thin copper wire wound round the water-jacket of the crucible as a treble layer. It was found that the stirring action obtained was very effective, even with a current of only 0.2 amp. input to a treble layer winding of 20 gauge (B. & S.) enamelled copper wire. With 1.4 amp. the stirring was excessive. This method although considered essential at one time gradually faded into disuse as the operators gained experience, particularly after the adoption of the double melting technique. The double melting technique was to use the ingots produced from the first melt as the electrode for the second melt. The furnace used for the second melting is shown in Fig. 3, and is relatively simple compared with that used for the first melting. The main reason for the simplicity is the elimination of the arrangement for welding electrodes as melting proceeds, together with the internal mechanical feeding and the use of rollers for picking up the power. In the new furnace helium and argon were not employed as it was advantageous to use reduced pressure.

The ingots produced from the 2-in. square section sponge electrodes measured about 6 in. in diameter and after skimming the surface they were joined by pegs, or welds, and screwed to the water-cooled copper tube which carried the power.

The furnace is pumped down before starting to melt and in the arrangement described, the Bureau of Mines used a single stage mechanical backing-pump with a rated capacity of 110 c.f.m. The reason stated for melting under reduced pressure was to minimise the formation of gas cavities in the top of the ingots. It was reported that a pressure of 4 cm. was sufficient for this purpose. In general, the product from the second melting is a clean ingot which can, with little loss, be fabricated to sound metal. The use of reduced pressure does not always eliminate the gas cavities in the ingot tops although it does reduce them (it is believed by some operators that the cavities are shrinkage cavities and are not related to gas evolution). The work at the Bureau does not mention the presence of hydrogen in the zirconium ingots although it is well known that small amounts of hydrogen (as low as 10 p.p.m.) may cause loss of impact strength due to embrittlement and it is also known that the presence of hydrogen in titanium was the cause of fabrication troubles. The use of reduced pressure for melting zirconium is preferable to inert gas atmosphere because not only does it remove hydrogen but

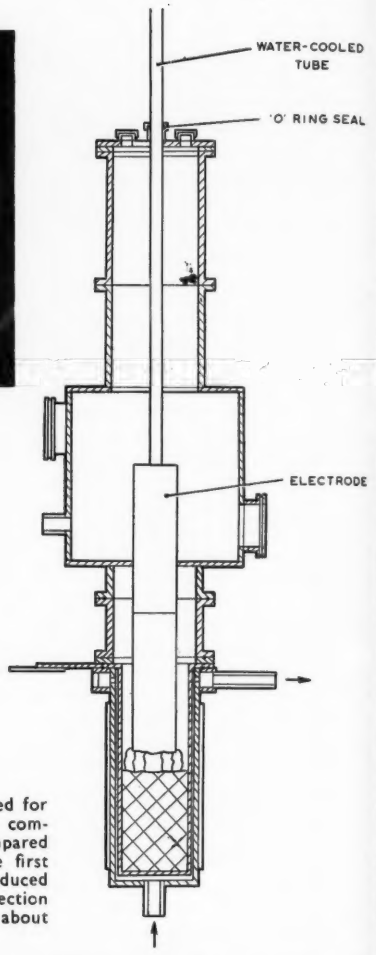

Fig. 3. The furnace used for the second melting is comparatively simple compared with that used for the first melting. The ingots produced from the 2-in. square section sponge electrodes are about 6 in. diameter.

ensures a more complete elimination of other impurities such as magnesium chloride and magnesium, and a still further advantage is that the depth of molten pool is increased as the pressure is lowered, in fact, it is possible to get depths of pool equal or greater than the diameter of the crucible.

Vacuum melting of zirconium and titanium is a very controversial subject. It is accepted that the pressure which is usually measured at the off-take from the furnace bears little or no relation to the pressure in the arc zone and that the electrode considerably restricts the rapid removal of gases from the melting zone. The difference of opinion is the usefulness of really low pressure equipment for gas removal, particularly the use of diffusion pumps capable of pumping the furnace down to the micron range, as indicated on the gauge at the off-take. There can be little dispute that the pressure in the melting zone is not that indicated by the gauge but nevertheless some tests do indicate that the hydrogen content of the ingots was lowered by using a diffusion pump backed with a mechanical pump as opposed to a straight mechanical. These tests cannot be accepted as final proof as it is very difficult to carry out experiments with all the variables controlled but there seems little reason to object to the claim that a lower pressure at the off-take should give a more ready removal of the gases particularly as the deeper pool which goes with the lower pressure should increase the time available for gas removal.

The successful arc melting of zirconium sponge is established and sound ingots of metal up to 1,000 lb. have been obtained with little loss of metal and at a low power consumption. Modern melting equipment would resemble the furnace used for the second melting and the special chamber for welding the pressed bars, while melting could be dispensed

with and the bars, pre-welded in an inert atmosphere, could be melted in much the same manner as described for the second melting. The incorporation of an electronic device to control the distance between the electrode tip and the molten pool is an essential part of arc melting units designed to produce large ingots as it is impossible otherwise to maintain this important control as melting proceeds so rapidly.

Fabrication

Pure zirconium has a hexagonal close-packed (alpha) structure at temperatures up to 865°C and a body-centred cubic (beta) structure above this temperature. All wrought zirconium shows preferred grain orientation, but this behaviour does not appear to cause any fabrication difficulties.

Zirconium and its alloys with a Brinell hardness of less than 200 are readily hot worked by forging and rolling. The formation of a layer of oxide which occurs during the heating is advantageous in preventing seizing to the working surfaces. In extrusion and drawing processes special precautions have to be taken to prevent galling of the metal surface.

Whilst operations on a laboratory scale are generally performed on metal that has been heated to the working temperature in electric furnaces in an inert atmosphere, it is more usual on an industrial scale to use conventional steel works furnaces heated by oil or gas. Under such conditions it has been found possible, provided overheating and flame impingement are avoided, to work the metal without appreciable contamination. It is generally recognized that the use of such furnaces tends to introduce hydrogen and if this is excessive it will cause embrittlement. Hydrogen may be removed from zirconium by heating at about 1,000°C in a high vacuum but this adds to the expense of processing. Ingots must be free from defects and these are removed by rough machining followed by grinding of local bad spots.

The heating schedule depends on the size of the material being treated. Four-inch diameter ingots are heated for not more than one hour at 980°C and ingots as large as 12 in. diameter are soaked at this temperature for two hours before forging; the ingots being charged into the furnace at top temperature without preheating. The oxide penetration resulting from this treatment is not appreciable. Forging can be started at 850°C and continued until the temperature has dropped to 650°C. Zirconium alloys such as zirconium containing 2.5% tin require a rather higher temperature. During hot working the oxide skin becomes a hard tenacious scale which requires shot blasting to remove it, whilst a final pickle in a mixture of nitric and hydrofluoric acids is required to give a clean surface.

Hot rolling can be performed with conventional steel works equipment just as in the case of the other working operations, but it is most desirable that the working required should be well within the capabilities of the equipment in order to minimise the time of manipulation and so avoid reheating and further oxidation. Continuous strip rolls have been used successfully to produce zirconium sheet. After forging to slab or billet it is advisable to remove the oxide skin before proceeding to roll otherwise the scale may be worked deeply into the surface of the metal. The scale is removed as described above using a pickling solution of 8 to 12% nitric acid and 2 to 4% hydrofluoric acid (the composition of the pickle solution is important if hydrogen contamination during pickling is to be minimized). Heating as before can be performed satisfactorily in a furnace fired by oil or gas. Sheathing of the metal with steel to minimise oxidation during heating and working is not required if the billets are reasonably large and heating and working time kept to a minimum. Rolling may be performed at a slightly lower temperature than forging, say 800°C, but the operation must not continue when the temperature has dropped to 650°C. The zirconium alloy with a 2½% tin addition requires a slightly higher temperature starting at 850°C and finishing at 700°C. The rolling operation produces a very tough scale which is difficult to remove and blasting followed by pickling is required to produce a clean surface suitable for cold rolling.

Zirconium does not work-harden very rapidly and reductions up to 10% may be performed with a total reduction of about 35% before annealing is required. Annealing is generally performed at 700°C to 850°C.

Hot extrusions have been performed at temperatures ranging from 750°C to 1,000°C. The metal may be extruded bare or in a sheath. In the former case it is necessary to use lubricants such as an oil carrier with graphite flakes or colloidal graphite to prevent seizing and welding to the dies and tools. If copper is used as a sheathing material the danger of seizing is avoided and lubrication is simplified. Steel, copper and some of the harder brasses have been used as sheathing materials and some work has been done with the Ugine-Sejournet method of glass lubrication. Reports from the U.S. state that in the production of tubes by extrusion, the billet has to be bored, or hollow castings used as no successful piercing operation has been achieved, but zirconium tubes can be produced by piercing solid billets and the practice is becoming established in the U.K.

Swaging zirconium does not present any difficulty as long as annealing is performed at intervals. Cold reductions of 10 to 15% are normal whilst 50% in smaller rods is possible. Zirconium with a hardness which is in excess of 90 RB is usually heated to about 400°C before swaging. Lubricants are not required and the oxide skin prevents seizing.

The drawing of wire and rod was difficult owing to the tendency of the metal to seize but special lubricants prepared from molybdenum disulphide have overcome most of the difficulties. The molybdenum disulphide is applied in the form of a dispersion in lacquer. Satisfactory results are achieved with conventional lubricants such as soap compounds if the metal surface is prepared by treatment with an aqueous solution containing 0.1 to 0.5% by volume hydrofluoric acid and 1% orthophosphoric acid.

Copper in the form of a sheath or deposit has been employed as a lubricant. If a sheath is employed it serves to give some protection during annealing in air. The copper is removed by acid treatment after the last draw but molybdenum disulphide may be used to give a better finish for the last draw after the removal of the copper. (There is still the problem of the removal of the molybdenum disulphide.)

Deep drawing and cupping of zirconium are readily achieved so long as a suitable oxide surface is prepared to act as a surface for the coating and prevent metal to metal contact. A suitable coating is produced by heating for short periods, say up to one minute, at 750°C to 800°C, this treatment is generally sufficient for annealing which must be performed after about 35 to 40% reduction.

Tube drawing of zirconium can be performed on tubes produced by welding sheet or by drilling billets but it is more usual to operate with the product of the extrusion press. The higher the purity of the metal the easier it is to draw and the further the operation may proceed before annealing is required. Single passes of 40% reduction are possible although 15 to 20% are more normal. Total reductions up to 60 to 70% before annealing are usual. Copper coatings have been employed succesfully, the coating serving two purposes; lubrication, and protection during annealing.

The extruded hollow from the press is best treated by passing through a "cold reducing" machine. This operates on "pilger" principles and simulates tube rolling on a mandrel. The main advantage is that it will operate with the minimum of surface preparation on the tube and will make reductions of up to 40% per pass in the cold.

Zirconium can be machined to give a good finish if its galling tendency is appreciated and care taken to counteract it. Hard metal tools are suitable for the work but a prerequisite of success is the preparation of the cutting edge.

Blunt tools cause rapid and excessive work hardening and give a bad surface finish. Fine zirconium cuttings are readily ignited and the use of dull edged tools can cause excessive heating of this material and a fire may result.

Despite early fears that the reactivity of zirconium towards oxygen and nitrogen might make it difficult if not impossible to obtain ductile welds, the metal can be welded successfully provided inert-gas-shielded arc-welding methods are used. In fact, zirconium is a more suitable medium for welding than some of the common metals. The low coefficient of thermal expansion is an advantage as it lessens distortion during welding. Another advantage is the solution of any oxide that may be formed whilst welding. Fluxes are not required and satisfactory welds are readily obtained, provided nitrogen contamination is avoided. This can be obtained by the use of a pure inert gas particularly if the welding is performed in a gas-tight box, although it is difficult to obtain such perfect welding conditions when large equipment has to be fabricated. The weld metal has good corrosion resistance properties and some work indicates that for certain media, the weld metal is more corrosion resistant than the parent metal but it has not been established whether the difference is due to an improvement in the weld metal or a deterioration in the parent metal.

Present Position

The present position of zirconium production is that a plant owned by the Carborundum Metal Co. Inc. at Akron, N.Y. near Niagara, has been in operation for about two years at an annual rate of 150,000 to 200,000 lb. of hafnium-free zirconium. All this metal is produced for the Atomic Energy Commission's account. Smaller quantities of zirconium containing hafnium have been produced. The plant at Akron is a completely integrated unit including conversion to zirconium chloride, removal of hafnium, rechlorination, reduction to sponge, and final preparation as crushed metal ready for melting. Melting has not been performed at the Carborundum Metal plant except on an experimental scale. Sponge has been shipped to Firth Sterling of Pittsburgh and Allegheny Ludlum's plant at Watervleit, near Albany, New York, for consolidation by arc melting. Ingots up to 1,000 lb. in weight have been produced. Carborundum Metal propose to commence melting their own sponge before the end of this year, and will produce ingots up to 1,000 lb. The production policy of the Titanium Alloy Manufacturing Co. in the U.S. is in the course of consideration. The Bureau of Mines at Albany, Oregon, stopped production in the middle of 1955, but it has recently been announced in the U.S. Press that the Albany plant is definitely scheduled for "reactivation" under the control of the Wah Chang Corporation of New York. The Wah Chang Corporation have been awarded a contract with the Atomic Energy Commission for the supply of about 300,000 pounds of zirconium a year for two years. The contract is to terminate June 30, 1958, but the contract contains a renewal clause.

Horizons Incorporated at Cleveland, Ohio, have probably done more work on electrolysis than anyone else. The reported work indicates that metal was produced at a rate of 4 to 6 lb. per hour. This metal when arc melted had a B.H.N. 150 to 165, and the oxygen, nitrogen and carbon contents were 0.06 to 0.09%, average 0.0035%, and 0.02 to 0.06% respectively. Although the process has produced metal of satisfactory quality it possesses many disadvantages which have to be overcome before commercial production is possible.

The Atomic Energy Commission's new proposals asking industry to expand production will undoubtedly indicate the position of new developments because it is an opportunity for companies with such developments to put them on a production basis. Recent reports show that three new zirconium plants are to be built and, in addition, the Atomic Energy Commission has arranged a contract for the delivery

Zirconium

La première partie de cette série d'articles sur le zirconium traitait de la production du métal aux Etats-Unis et dans le Royaume Uni, obtenu en général par le procédé Kroll. Dans cette seconde partie la préparation du métal qui suit est exposée débutant par la fusion et la formation des alliages. La dissolution incomplète et les points d'ébullition différents créent des problèmes dans la préparation des alliages tel que le "Zircalloy" que l'on rend homogène par un procédé dans laquelle les additions, préalablement comprimées en globules sont automatiquement ajoutées au mélange. Le métal liquide peut être agité par une technique utilisant un champs magnétique. On a obtenu des lingots pesant jusqu'à 500 kg. avec peu de perte de métal et avec une consommation de pouvoir peu élevée.

Le zirconium peut être laminé à chaud avec le matériel normal d'une aciérie, bien qu'il soit essentiel de travailler rapidement pour éviter trop de temps passé à une température élevée. On utilise des solutions de décapage composées d'un mélange d'acide nitrique et d'acide fluorhydrique. On peut forger à 850°C et continuer jusqu'à 650°C. Le métal recuit entre 700 et 850°C tandis qu'il a été extrudé entre 750°C et 1.000°C. Le zirconium peut être estampé sans lubrifiant, et en utilisant des lubrifiants solides tel que le disulphure de molybdène le tréfilage est possible. On peut obtenir un fini excellent par l'usinage avec des outils affilés.

Zirkonium

Der erste Teil dieser Serie über Zirkon behandelte die Gewinnung des Metalles in den Vereinigten Staaten und in Grossbritannien meistens nach dem Krollprozess. In dem zweiten Teil wird die nachfolgende Behandlung, das Schmelzen und die Bildung von Legierungen besprochen. Unvollkommene Lösung und verschiedene Siedepunkte führen zu gewissen Problemen bei der Herstellung von Legierungen wie z.B. "Zirkalloy," die durch ein besonderes Verfahren homogen gemacht werden müsen, bei welchem u.a. Zusätze erst in Kügelchen gepresst und dann der Mischung automatisch zugeführt werden. Das flüssige Metall wird durch Behandlung im magnetischen Feld gemischt. Man kann Barren von 500 kg. mit geringem Verlust an Metall und ohne grossen Kraftverbrauch erhalten.

Zirkon kann warm auf konventionellen Walzeinrichtungen eines Stahlwerks ausgewalzt werden; Schnelligkeit is wesentlich, um unnötig langes Verbleiben im warmen Zustande zu vermeiden. Alz Beizlösungen werden Mischungen von Salpetersäure und Flussäure benutzt. Schmieden kann manes bei 850°C bis herunter zu 650°C. Das Metall wird zwischen 700 und 850°C geglüht; zwischen 750 und 1000°C kann es verpresst werden. Zirkon kann ohne Schmierung im Gesenk geschmiedet werden, mit festen Schmiermittlen wie z.B. Molybdendisulfid kann man es in der Drahtziehbank verarbeiten.

Ausgezeichnete Oberflächen können durch Bearbeiten mit gut geschliffenen Werkzeugen erzielt werden.

Zirconio

La Parte 1a. de esta serie sobre el zirconio se relacionaba con la producción del metal en los Estados Unidos y en el Reino Unido, mayormente por el proceso Kroll. En esta segunda parte, se discute el tratamiento subsiguiente, comenzando con el derretimiento y la formación de aleaciones. La solución incompleta y la diferencia entre puntos de ebullición crean problemas en la fabricación de aleaciones tales como "Zircalloy", las que se hacen homogéneas por un procedimiento en que primero se comprimen los aditivos en balines o pastillas, alimentándoselos automáticamente a la mezcla. El metal líquido puede ser agitado mediante una técnica de campo magnético. Se han obtenido lingotes hasta de 500 kg. con poca pérdida del metal y con bajo consumo de energía.

El zirconio puede ser laminado en caliente con el equipo clásico de la fabricación de acero, aunque es esencial la rapidez de tratamiento para evitar que quede un tiempo innecesario en el estado caliente. Las soluciones de decapado, compuestas de una mezcla de ácidos nítricos e hidrofluóricos son empleadas. El forjado puede hacerse a 850°C continuándose hacia abajo a 650°C. El metal es recocido a 700-850°C mientras que se han hecho extrusiones entre 750° y 1000°C. El zirconio pue ser estampado sin lubrificación y, con lubrificantes sólidos tales como el disulfuro de molibdeno, es posible el estirado de alambre. Con herramientas afiladas, se puede obtener un acabado excelente al mecanizarse.

of some 200,000 pounds of zirconium from Japan, deliveries to begin this year and end 1957. The U.S. Atomic Energy Commission's immediate requirements are about 11 million pounds of metal to be produced within the next five years.

In the United Kingdom the position is rather different. Production was started in 1950 on a small scale, about five tons per annum, by Murex Ltd., Rainham, Essex, operating the Kroll process. This plant was built to enable experience in production to be gained, and to provide sufficient metal for exploration of the uses in industry. It was hoped that long before now a large plant would have been built and operated on the same lines as that at Carborundum Metals but nuclear developments in the U.K. have taken a different road from that in the U.S.A. Production at Rainham has been increased to about 10 tons of sponge per year. Practically the whole of this metal is hafnium containing. Small amounts of hafnium-free metal have been produced using hafnium-free chloride produced by Magnesium Elektron Ltd., and it is expected that the amount of hafnium-free metal will increase. The bulk of the metal has been consolidated by melting in graphite crucibles but recently arc melting with consumable electrodes on a small scale has been developed and arrangements are being made to expand production by this method.

Despite the low production in the U.K., all forms of zirconium have been available for some time and, in fact, zirconium was first available to industry in this country—in the U.S.A., it was restricted to nuclear developments.

Recently Krupps in West Germany announced that zirconium sheet is in production and will be selling at an estimated price of £40 per lb. This is believed to be hafnium free.

So far as other countries are concerned, it is difficult to know what is going on. Undoubtedly many companies are interested in zirconium and are investigating production on a laboratory scale but no other producers are known except possibly the Pechiney Compagnie de Produits Chimiques et Electrometallurgie, in France, where there is production on a small but unknown scale. Finally, so far as the production process is concerned most, if not all, production problems appear to have been overcome and metal of satisfactory quality is available in all forms. Supplies of ore are ample for any foreseeable future requirement and with the development of arc melting the production of ingots is no longer a problem. Working the metal requires care but sufficient experience has already been acquired to ensure the production of satisfactory components. However, there is one important task that remains: to reduce the costs of production and so expand the application.

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Training Nuclear Engineers at Oak Ridge

THE training of engineers for the many fields now opening out in the nuclear industry has already become a major problem, and it is of interest to note what is being accomplished in America in this direction. The chief role is being played by the Oak Ridge School of Reactor Technology, through which 400 students have passed, now all engaged in research and development in atomic energy in industrial organizations, in the U.S. Atomic Energy Commission and the National Military Establishment. No fewer than 50 of the leading manufacturers in America, covering almost every field of industry, employ men who have passed through the Oak Ridge School.

The seventh course at the Oak Ridge School begins in September next, and is of one year's duration. The students are very hard worked, as the only holiday allowed is one week in June, and it is expected that they should devote 60 to 70 hours a week to the school programme. Applicants for admission must be sponsored by the Atomic Energy Commission or its contractors, other appropriate government agencies or their contractors, or industrial organizations having an active interest in the development of reactors and/or reactor components. A bachelor degree in chemistry, engineering, metallurgy, physics or engineering physics is essential, in addition to an "outstanding academic record". The school is part of the Oak Ridge National Laboratory, which is the largest laboratory in the United States devoted exclusively to research and development in all phases of nuclear energy, and extensive large-scale reactor development work is being performed. It is natural, therefore, that a good deal of the instruction at the school is provided by scientists and engineers actually engaged in the laboratory's research and development programme.

The subjects of the course are reactor analysis, reactor chemical technology, reactor component design engineering, reactor controls and reactor systems, reactor engineering, experimental reactor physics, reactor materials, reactor shielding and reactor design problems. It is the purpose of the school to compress the time normally required for experience alone to develop a graduate engineer into a reactor engineer.

There is no tuition fee for students who are government employees, or who are sponsored by Atomic Energy Commission contractors, but a fee of $2,500 is charged for students sponsored by private industry or contractors for government agencies other than the Atomic Energy Commission. No academic degree is granted, and the school is only available to American citizens.

Students conducting experiments on a graphite-uranium lattice system. Age of the students extends over a wide range.

American Reactor Programme

Summarized details are given of the power reactor experiments completed and under construction in the U.S.A.E.C. programme. So far as nuclear power stations for electricity supply are concerned, seven are planned, using five different types of reactor: pressurized water, boiling water, sodium graphite, fast breeder and homogeneous. The first station, that at Shippingport, is due to be completed next year.

IT is anticipated that in 1957 the first civilian nuclear power station in the United States will be completed, and that by 1960 five further plants will be operating, developing a combined total of 839,000 kW whilst a seventh nuclear station of 150,000 kW will be available in 1962. In addition, the Atomic Energy Commission decided that development of smaller nuclear power plants should be carried out, and invited manufacturers to submit plans for installations limited to specific power ranges, between 5,000 kW and 40,000 kW. Seven proposals were received and it is understood that they are likely to be accepted; no doubt in view of their smaller size some of them will be completed before the larger power stations.

Three-Part Programme

The Atomic Energy Commission power reactor development programme, as pointed out by Mr. W. Kenneth Davis, director of the division of reactor development of the Commission, in a paper before the American Association for the Advancement of Science* comprises three main parts: the development of basic technology, the testing of concepts by integrated reactor experiments, and the power reactor programme with the co-operation of industry. The developments mentioned above represent the third part of this programme.

A good deal of publicity has been given to the various reactor experiments in the United States, and it will suffice to summarize them only. Table 1 details those in the A.E.C. programme, completed or under construction. One reactor has been completed and subsequently dismantled, and two others are in operation.

Experimental Breeder Reactor No. 1 developed by the Argonne National Laboratory, has been in successful operation for some time. Whilst most of the reactors under serious consideration are thermal types, EBR-1 operates with a fast neutron spectrum. Another reactor (Borax III) in operation is one of a series of similar reactors to test the feasibility of boiling water in the core of the reactor and utilizing the steam directly in a turbine.

*"Industrial Applications of Atomic Power."

In March, 1954, the Atomic Energy Commission announced a five-year programme of power reactor development, and five types of reactor were selected for further experiments. Other reactor experiments are shown in Table 1, part II. The Sodium Reactor Experiment (SRE) is being fabricated by Atomics

TABLE I—SUMMARY OF MAJOR POWER REACTOR EXPERIMENTS—Part 1

	EBR No. 1	EBR No. 2	HRE No. 1	HRE No. 2	BORAX III (1)	EBWR	SRE
Location	NRTS, Idaho	NRTS, Idaho	Oak Ridge	Oak Ridge	NRTS, Idaho	Argonne	Santa Susana, Cal.
Responsible Laboratory	Argonne	Argonne	Oak Ridge	Oak Ridge	Argonne	Argonne	Atomics Intl. (NAA, Inc.)
Heat Output	1.4 MW	62.5 MW	1 MW	5-10 MW	15 MW	20 MW	20 MW
Generat. Capac.	150 kW	17.5 MW	150 kW	300 kW	2.4 MW	5 MW	7.5 MW
Cost, Reactor (2)	$2.7 M.	$15.3 M.	$1.1 M.	$1.8 M.	$0.6 m.	$3.6 M.	$5.3 M
Cost, Programme (3)	$6 M.	$39.6 m.*	$12.8 M.	$38.8 M.*	$2.8 M.	$19.7 M.*	$14.4 M**
Start of Constr.	1949 (fall)	1956	1951 (Mar.)	1954 (Jul.)	1954 (Sep.)	1955 (Jun.)	1954 (Aug.)
Reactor Critical	1951 (Aug.)	1958	1952 (Apr.)	1956	1955 (Jun.)	1956	1956
Date Operation at Full Power	1951 (Dec.)	1959	1953 (Feb.)	1956	1955 (Jul.)	1956	1957
Reactor Outlet Temperature	600° F.	1,000° F.	480° F.	570° F.	417° F.	488° F.	960° F.
Reactor Pressure	about 100 p.s.i.g.	about 100 p.s.i.g.	1,000 p.s.i.g.	2,000 p.s.i.g.	300 p.s.i.g.	600 p.s.i.g.	300 p.s.i.g.
Amount Uranium Fuel	48 kg.	150 kg. or 90 kg. Pu.	3 kg.	4 kg.	15 kg.	4,500 kg.	2,100 kg.
Enrichment, U235	about 90%	45% or 24% Pu	about 90%	about 90%	about 90%	1.4%	2.9%
Moderator	None	None	H_2O	D_2O	H_2O	H_2O	Graphite
Coolant	Sodium-Potassium	Sodium	Circulating Fuel Solution	Circulating Fuel Solution	H_2O	H_2O	Sodium
Control Method	Movable Blanket and U 238 Rods	Movable Blanket and Fuel Rods	U Conc. and Temp. Coeff.	U Conc. and Temp. Coeff.	Control Rods and Chem. Solu.	Control Rods	Control Rods
Steam Conditions	400 p.s.i.g. 540° F.	1,800 p.s.i.g. 900° F.	200 p.s.i.a. saturated	520 p.s.i.a. saturated	300 p.s.i.g. saturated	600 p.s.i.g. saturated	600 p.s.i.g 825° F.

* Cost of programme is estimated total cost for development of concept from July 1953 to July 1958.
** Includes turbogenerator by Southern California Edison Co.
(1) Borax III is part of the EBWR programme. (2) Including building to house reactor and fabrication of fuel elements for first charge but not fissionable material. (3) Including reactor.

TABLE I—SUMMARY OF MAJOR POWER REACTOR EXPERIMENTS—Part 2

	LAPRE I	LAPRE II	LAMPRE	OMRE	LMFRE
Location	Los Alamos	Los Alamos	Los Alamos	NRTS, Idaho	
Responsible Laboratory	Los Alamos	Los Alamos	Los Alamos	Atomics Intl. (NAA, Inc.)	Brookhaven
Heat Output	2 MW	1.3 MW	About 1 MW	16 MW	5 MW to 10 MW
Generat. Capacity	None	None	None	None	None
Cost, Reactor (2)	$0.7 M.	$0.1 M.		$0.875 M.	
Cost, Programme (3)	$2.2 M.	$0.28 M.	$3 M.	$1.8 M.	$10 M. to $12 M.
Start of Constr.	1955	1955	1958	1956 (Jan.)	
Reactor Critical	1956	1956	1959	1956	
Date Operation at Full Power	1956	1956	1959	1957	
Reactor Outlet Temperature	805° F.	600° F.		530° F.	
Reactor Pressure	About 3,900 p.s.i.g.	About 800 p.s.i.g.		300 p.s.i.g.	
Amount Uranium Fuel	8.4 kg.	7.7 kg.	Molten Pu. Alloy	20 kg.	
Enrichment, U235	About 90%	About 90%		About 90%	
Moderator	H_2O	H_2O	None	Diphenyl	Carbon
Coolant	H_2O	H_2O	Sodium-Potassium	Diphenyl	Circulating Fuel Sol. in Bismuth
Control Method	Control Rods and Temp. Coeff.	Solution Vol., Temp. Coeff., Movable Reflect.	Movable Reflector	Control Rods	U Conc., Temp. Coeff., Control Rods
Steam Conditions	3,600 p.s.i.a.	600 p.s.i.a. Sat.	None	None	None

(2) Including building to house reactor and fabrication of fuel elements for first charge but not fissile material.
(3) Including reactor.

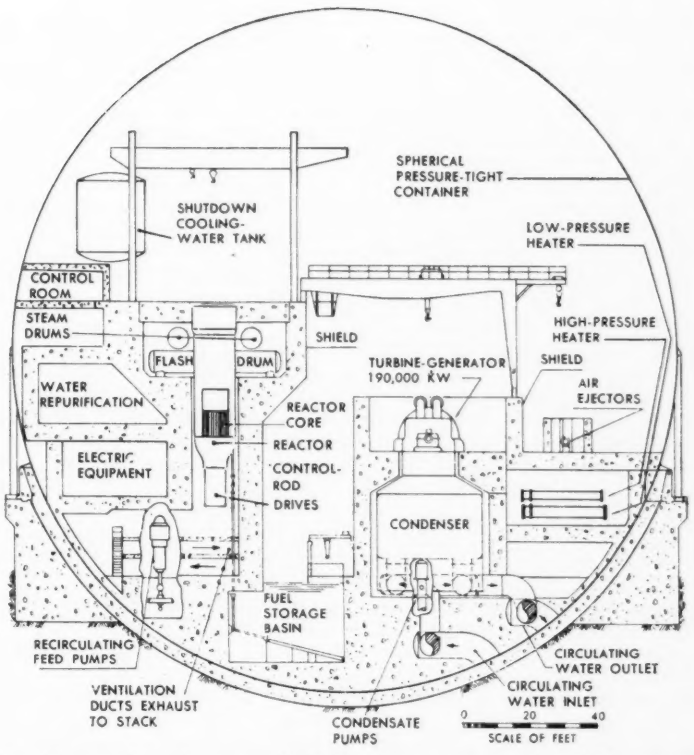
International, a division of North American Aviation Inc. It uses liquid sodium as the coolant and graphite as the moderator. The Los Alamos Power Reactor Experiments Nos. 1 and 2 (LAPRE) are aqueous homogeneous reactors using a phosphate solution instead of sulphate, which allows higher concentration of uranium and smaller core sizes. Both reactors will be in operation this year.

The Organic Moderated Reactor Experiment (OMRE) involves the use of an organic material for moderation and cooling. This is expected to be in operation late this year and will be a minimum type experiment for establishing the technical feasibility of using organics in the reactor.

In the Liquid Metal Fuel Reactor (LMFRE) the uranium is dissolved in liquid bismuth, which may also act as a heat transfer medium. The bismuth can be pumped through the reactor and the heat exchanger, or be contained within the core.

Research for which Brookhaven National Laboratory is responsible, has shown that graphite and a low chrome steel are suitable materials for construction. It is possible to achieve temperatures of the order of 1,400° F at atmospheric pressure. Components suitable for use with this reactor have not yet been completely developed. It is expected that the reactor may be in operation in 1959.

It is of interest that reactors of this type, as well as others, may be used with a suitable gas as the coolant, and a closed cycle gas turbine employed for power production. No condenser cooling water would be required and the cycle efficiencies that seem realizable are quite high, perhaps 40%. The temperatures necessary for efficient operation are around 1,200° to 1,400° F but the necessary reactor technology has not yet been developed.



Provisional layout of the Commonwealth Edison power reactor. Of the boiling water type the plant will have a generating capacity of 180 MW and will be completed in 1960.

TABLE II—SUMMARY OF PROTOTYPE POWER REACTOR PLANTS PROPOSED

Company	Westinghouse* and Duquesne Light Co.	Yankee Atomic Electric Co.	Consolidated Edison Co.	Commonwealth Edison and others	Consumers' Public Power District	Power Reactor Dev. Co. (Det. Ed. et al)	Westinghouse and Pennsylvania Power and Light
Location	Shippingport, Pennsylvania	Western Massachusetts	Indian Point New York	Near Chicago	Nebraska	Detroit Edison Service Area	P. P. & L. Service Area
Type of Reactor	Pressurized Water (PWR)	Pressurized Water	Pressurized Water	Boiling Water	Sodium-Graphite	Fast Breeder	Homogeneous
Thermal Power	236 MW	480 MW	500 MW	682 MW	250 MW	300 MW	
Gross Generating Capacity	100 MW	134 MW	236 MW**	180 MW	75 MW	100 MW	150 MW
Amount of Fuel	12 T natural U and 52 kg. about 90%	28,800 kg.	275 kg. U. and 8,100 kg. Th.	68,000 kg.	24,600 kg.	2,100 kg.	
Enrichment Per cent U235		2.7%	About 90% for U.	1.1%	1.8%	20%	
Moderator	H_2O	H_2O	H_2O	H_2O	Graphite	None	
Coolant	H_2O	H_2O	H_2O	H_2O	Sodium	Sodium	Fuel Solu.
Reactor Temp.***	540° F.	535° F.	500° F.	480° F.	925° F.	800° F.	
Reactor Pressure	2,000 p.s.i.g.	2,000 p.s.i.g.	1,500 p.s.i.g.	600 p.s.i.g.	300 p.s.i.g.	100-200 p.s.i.g.	
Steam Conditions	585 p.s.i.g. Saturated	600 p.s.i.a. Saturated	420 p.s.i.a. Saturated	600 p.s.i.a. 480° F.	800 p.s.i.g. 825° F.	600 p.s.i.a. 730° F.	600 p.s.i.a.
Estimated Cost of Reactor****	$27.7 M.	$174.4 M.		$34.2 M.	$13.5 M.	$36 M.	
Est. Cost of Turbo-Gen. Plant	$10 M.	$16 M.		$10.8 M.	$10.8 M.	$9 M.	
Total Estimated Plant Cost	$37.7 M.	$33.4 M.	$55 M.	$45 M.	$24.3 M.	$45 M.	
Cost per kW	$370	$246	$230	$250	$320	$540	
Estimated Completion Date	1957	1959-60	1960	1960	1958-9	1959-60	1962

* This reactor is being built by the AEC; Westinghouse and Duquesne are prime contractors to the AEC.
** Includes 96,000 kW of conventional superheating capacity.
*** Average temperature of coolant in reactor.
**** Not including research and development, fabrication of fuel elements for first charge, or nuclear materials. Fuel element fabrication and nuclear materials are included in fuel costs.

The Atomic Energy Commission announced a power demonstration reactor programme in January, 1955, for the purpose of "accelerating the development of commercial power reactors, and to encourage the construction of prototype reactors by industry or by publicly owned electric supply companies." The A.E.C. will underwrite part of the cost of research and development.

Details of all of the proposed plants are shown in Table II and particulars of the manner in which they will be financed are now available, the arrangements being different in the case of the various plants, for which it will be noted that five different types of reactor are proposed, namely: (1) pressurized water; (2) boiling water; (3) sodium graphite; (4) fast breeder and (5) homogeneous.

The pressurized light water reactor plant being built by Westinghouse and the Duquesne Light Co., is expected to be in operation towards the latter part of 1957. It is to be one of the U.S. Atomic Energy Commission's own experimental projects and will be largely financed by the A.E.C. The Duquesne Light Co., however, is furnishing the site, the generating facilities and the housing, also the

step-up sub-station and transmission facilities. The company will contribute $5 million towards the cost of the development of the reactor. The role of the Westinghouse Electric Corporation is that of prime contractor to the A.E.C. for the development and construction of the reactor and its associated equipment.

The A.E.C. has recently approved, as a basis for contract negotiations which are now under way, the proposals submitted by the Yankee Atomic Electric Co. for the development, design, construction and operation of a pressurized light power plant in the State of Massachusetts for the demonstration of economic feasibility of this type of nuclear power plant.

The proposal asks for a certain amount of A.E.C. financial assistance in the research and development required, and for the Commission to waive the charge for the use of fuel until July 1, 1962. Otherwise, the Yankee Atomic Electric Co. intends to pay all construction and operating expenses.

The Consumers Public Power District of Nebraska has submitted a proposal for the development, design, construction and operation of a sodium-cooled, graphite-moderated nuclear power plant to demonstrate the economic feasibility of this type of reactor for the generation of electricity. The A.E.C. has approved this proposal as a basis for contract negotiations which are now proceeding. The Commission would pay for and retain the title to most of the reactor and its associated equipment, would underwrite pre-operational research and development costs up to a certain maximum amount, and waive the normal charge for the use of special nuclear material up to July 1, 1962. The Consumers Public Power District will furnish the site, buildings and generating equipment and transmission facilities and will pay all operating costs.

Fast Breeder Type

The proposal submitted by the Power Reactor Development Co. (Detroit Edison Co. and others) calls for the development, design, construction and operation of a demonstration nuclear power plant using the fast breeder reactor principle. This proposal has been accepted and contract negotiations with the company are under way. The company proposed that the A.E.C. perform within its own facilities and at its own expense a fixed amount of pre-operational research and development; that the A.E.C. underwrite a fixed amount of the cost of pre-operational research and development to be obtained by the company from private sources and that the A.E.C. waive its normal use charges for special nuclear material up to July 1, 1962. The company proposes to pay all construction costs and all operational expenses.

The Consolidated Edison Co. of New York has submitted an application to the A.E.C. for a licence to construct and operate a pressurized light water nuclear power plant. This is entirely a private venture and does not ask any A.E.C. financial assistance. The licence application is under consideration by the A.E.C. and it is anticipated that a construction permit will be issued soon.* Consolidated Edison is making no payments to the A.E.C. as a development charge, but, like many hundreds of other American companies, has access to the Commission's technical research and development information pertaining to power reactors.

The Commonwealth Edison Co. of Chicago has applied for a licence to construct and operate a boiling water reactor power plant. This application is also under consideration by the A.E.C.* This plant will be financed entirely by the company.

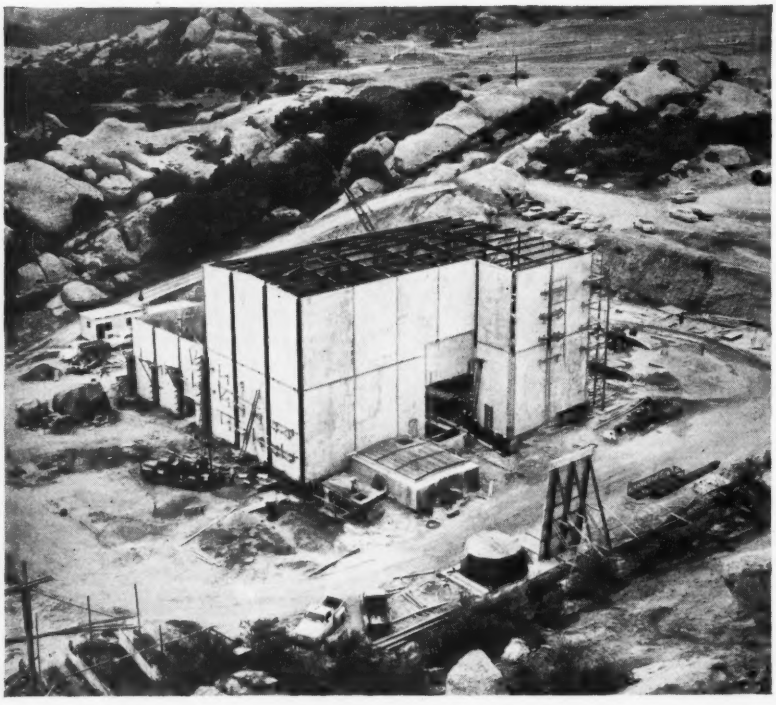
The Pennsylvania Power and Light Co. has announced its intention to build and have in operation by 1962 a large-scale nuclear power plant. The company has engaged the Westinghouse Electric Corporation to explore a number of promising designs, and current emphasis is on consideration of the aqueous homogeneous reactor type. No application has as yet been submitted to the A.E.C. for a licence. It is anticipated that this project will be undertaken solely at private expense.

Closed-Cycle Gas Turbine

Whilst all the proposals for these reactors involve the employment of steam turbo generating plant, it is of interest to learn that one of the smaller plants which are now projected is to be designed with a view to the utilization of an Escher Wyss closed-cycle gas turbine.

With respect to the seven proposals for small-scale nuclear power plant submitted under the second round of the power demonstration reactor programme, the A.E.C. Selection Board appointed for this purpose is now reviewing the situation. It is not possible to say when decisions will be reached. For the most part, the types of assistance the A.E.C. announced it would consider for these smaller plants are the same as for the first round in the demonstration programme. It is hoped that as much private resources and effort as possible will be devoted to these projects.

For both demonstration plants and plants to be built under licence application with no A.E.C. financial assistance, the A.E.C. expect the companies involved to be responsible for their design and construction.



The Sodium Graphite Experiment (SRE) reactor under construction by Atomics International for the A.E.C. It will have a generating capacity of 7,500 kW and is due to be in full operation early next year.

*Permit granted—see World News.

Fixation of Radioactive Effluent

Amongst new processes which have been proposed for the storage and disposal of radioactive wastes is the absorption and fixation of the activity on siliceous minerals. Two general methods are discussed and consideration is also given to self-fixation by utilizing the heat generated by the internal radiations.

by
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ONE of the more promising new approaches to the treatment[1] of radioactive effluent appears to be that based on the conversion of liquid wastes to solid wastes by absorption on siliceous materials which, on firing to a high temperature, retain the activity in a form which is not leached appreciably by natural waters, so that the solid wastes may be safely stored.[2] A basically similar process has been suggested for concentration and disposal of very dilute, low activity wastes, in which the concentration achieved by uptake on a synthetic ion-exchange resin is increased further by ashing the resin after use.[3] The breakdown of organic ion-exchange resins, however, when subjected to high radiation dose-rates would preclude the use of such materials for the treatment of highly-active wastes. Attention has therefore been given to inorganic ion-exchange materials.

Ion-Exchange Methods Involving Clays and Soils

The clay minerals exhibit a wide range of capacities for exchange of cations, from 5-10 milliequivalents (meq.) per 100 g of clay for the kaolinite minerals characteristic of china clay to 80-150 meq./100 g for montmorillonite, as found in fullers earth and in bentonite; owing to their commercial importance, their properties have been very fully studied.[4] The cations present in the clays may be exchanged for other cations present in solution when the clay is suspended in the latter, so that by a suitable choice of conditions a radioactive solution may be decontaminated by treatment with fullers earth or bentonite. Furthermore, on heating to temperatures of 1,000° C or higher, water is irreversibly lost from the clay and the structure alters in such a manner that the cations are irreversibly fixed against leaching; the material is converted to a silica structure in which the cations are firmly held. Such a product could be safely stored without loss of activity to the surroundings.

This method was first applied using montmorillonite,[5] employing a column technique to achieve a good degree of decontamination; in addition, the use of columns is well suited to the remotely controlled processing which would be required for very high activity levels. In their natural state the clays are unsuitable for column operation, since the very small particle size would lead to an unduly high pressure drop across the column; difficulties might also arise due to swelling in salt solutions and blockage by fines. This difficulty was overcome by mixing the clays to a paste with water (with or without the aid of soil conditioners) and extruding them in the form of "worms" into a water-filled column. The packed column could then be operated until it was saturated, after which it would be removed, dried, and the clay fired to fix the activity. Several columns may be operated in series, a fresh column being added at the tail of the line as each saturated column is removed from the head. Table 1 shows the degree of fixation achieved with fission-products adsorbed on montmorillonite.

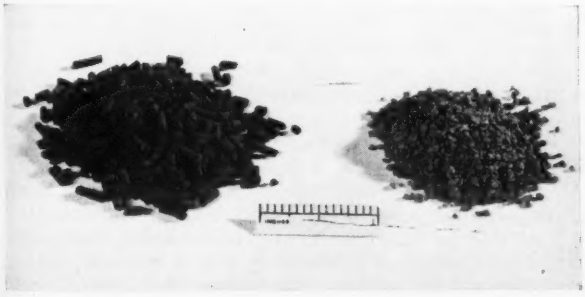

Fig. 1. Silica-bonded granular montmorillonite for use in ion-exchange columns: (left), extruded before firing; (right), lump form, not extruded.

Table 1. Removal of activity from 3-year-old mixed fission products* exchanged on montmorillonite.[5]

Leaching Solution	Contact Time (days)	Fixation Temperature	% Activity Removed
Distilled water	60	110	2.5
		675	0.41
		915	0.03
Sea-water	60	675	5.5
		775	0.42
		915	0.11
6M.HNO_3	60	110	90
		665	45
		720	37
		835	10

* Constituent isotopes in fission products:— Cs 137: 10.4%; Sr 90 and Y 90: 27%; Ce 144, Pr 144, Pm 147: 57%; Ru 106 and Rh 106: 5.4%.

In this method the clay must be extruded directly into the column, but an alternative process has been developed[6] which produces a more robust product which may be handled in the dry state and packed into columns in the usual manner. In this the clay is silica-bonded by treatment with partially hydrolyzed ethyl orthosilicate, followed by heating to decompose the binder, giving a granular product having a good mechanical strength as assessed by both wet and dry friability tests (Fig. 1). Even at the relatively low temperatures employed there is some irreversible loss of exchange capacity, so that an optimum value of the firing temperature must be selected which gives good mechanical properties without serious loss of capacity; this is achieved at a capacity of ~ 35-40 meq./100 g. This material may be used for column operation at temperatures up to 70° C, and Table 2 gives data for the fixation of Ba^{2+} ions at different temperatures.

Table 2. Removal of Ba^{2+} from silica-bonded fullers earth with 1M.HNO_3.[6]

Firing Temperature °C	Appearance of Material	% Removed
900	Unfused	1.6
1,000	"	1.3
1,050	"	1.1
1,100	Fusion beginning	0.4
1,150	Partially fused	< 0.1* (Boiling acid)
1,300	Melted and fused	
1,500	to very hard glass	

* Limit of detection with specific activity employed.

As ethyl orthosilicate is a relatively costly material, attempts are being made to develop a cheaper process. As an alternative to the use of clays, the possibility of using a suitable soil has been investigated. Soils possess appreciable

exchange capacities, depending upon the amount and type of clay mineral present, and work has been in progress for some time directed towards the decontamination of low-activity effluent by passage through large soil beds.[7] The soil in question, a Lower Greensand, lends itself fairly readily to column operation without elaborate pre-treatment, and might prove to be a suitable and cheaper alternative to granular clays. The capacity is somewhat lower, but is still appreciable; viz., 20-30 meq./100 g. Experiments carried out so far have shown that this material is equally efficient in fixing activity on firing to high temperatures;[8] some figures are given in Table 3.

Limitations to Such Processes

Processes based on ion exchange as an initial step are dependent upon the capacity of the exchanger, which for the materials discussed above is in the range 20-100 meq./100 g. As the exchanger does not discriminate in favour of active ions, we require for efficient operation a minimum dilution of the active material with inactive products. But, as Glueckauf[1] has shown, the great bulk of the ionic content of highly-active wastes from present-day separation processes comprises nitric acid and extraneous inactive elements such as iron, chromium, nickel, uranium, and aluminium; in fact, on the basis of equivalents, the fission-products form only 1% of the total ionic content.

Any disposal process is judged ultimately by the completeness of removal of Cs 137 and Sr 90, which are the two longest-lived, highly active members—Sr 90 being extremely toxic in addition. The presence of large amounts of polyvalent ions and of hydrogen ions implies that very considerable quantities of exchanger would be necessary in order to ensure complete removal of Cs and Sr, as the contaminating ions are so much more strongly absorbed. In addition, the presence of so much acid would lead to a breakdown of the clay and loss of capacity. Unseparated wastes of this kind could thus only be disposed of by ion exchange if they were first neutralized to remove acid and unwanted inactive ions. This process has two disadvantages. First, if chemical neutralization is carried out, the final solution contains quantities of Na^+ or Ca^{2+} ions equivalent to those of the ions removed, so that the final situation is little better than the first; an alternative process would be to increase the pH by electrolysis through an anion-exchange membrane, a process which introduces no fresh cations.[9] Secondly, the sludge produced would carry down practically the whole of the activity except for Cs and Sr, so that a highly-active sludge disposal problem would arise. Although in theory the sludge would contain only medium-lived activities (and should therefore be suitable for disposal after 13 years storage), some Cs and Sr are invariably carried down, so that the sludge activity is long-lived unless re-cycling is carried out. The additional complications arising from sludge disposal are such that a process of this type is uneconomical compared with evaporation and storage as practised at present.

For these reasons the employment of an ion-exchange method is ruled out except for fission-products substantially free from external contamination; for example, it might be employed for the disposal of separated fission-products such as Cs 137 or Sr 90, or for the incorporation of these into irradiation units. In future operations it may find a use in disposing of relatively pure fission products arising in the gas phase above homogeneous reactors.

Alternatives to Ion Exchange

In an attempt to overcome the limited capacity and the need for prior separation, attempts are being made to incorporate the activity irreversibly into glasses or ceramics, using natural silicate minerals as bases into which the cations of the waste are fused. Most of the cations present in the wastes form glassy aluminosilicates at high temperatures, and some are capable of acting as fluxes in the fusion process; if soils are used, lime and alumina present in them are readily incorporated. As ion exchange is no longer involved, we can achieve much higher loadings, and it is not necessary to remove inactive contaminants; furthermore, the presence of acid may no longer be harmful, although it may exercise a secondary effect by enhancing the distillation of ruthenium on firing. As applied to the present separation process, the nitric acid solution of the mixed nitrates would first be mixed with the siliceous base (clay, soil, or mineral silicate) so as to achieve the maximum possible loading and to give a paste which could be cast or extruded, but which would not separate into two phases on standing. This would then be dried and fired to such a temperature that the activity was firmly fixed, and preferably to form a glass or ceramic in order to achieve maximum density and to give a product which could be readily handled. During the firing, acid would be driven off, nitrates converted to oxides, and the latter incorporated into the silicate structure. Alternatively, it might prove preferable to work with suspensions from which the acid had been removed and the insoluble hydroxides precipitated by neutralization before mixing with the absorbing material. Such a method would have the advantages of reducing volatilization of Ru and also of minimizing possible difficulties arising from decomposition of solid nitrates.

Two classes of cheap natural materials have been examined so far, but there are many other possibilities.

Natural mineral silicates—Some success has been achieved with nepheline-syenite, a natural aluminosilicate with a formula approximating to $(K,Na)AlSiO_4$.[10] When treated with an acid waste, silicic acid is liberated and a gel is formed; by adjusting the proportions correctly, the whole of the liquid may be absorbed by the gel. After drying, the gel may be heated until it melts ($\sim$1,250° C) to form a glass, from which the loss of activity on leaching with water is only $\sim 10^{-3}$ to 10^{-4}% per week. Although promising results have been obtained with synthetic fission-product solutions, it is too early

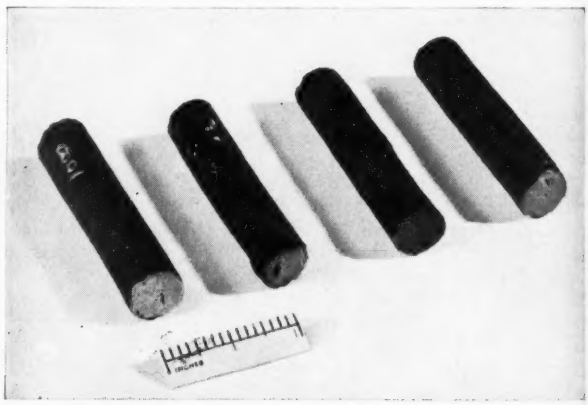

Fig. 2. Extruded and fired bricks, prepared from ball clay, alkaline fluxes, and synthetic concentrated fission-product solution. (English Clays Lovering and Pochin Ltd.)

yet to say how high a concentration of inactive ions can be tolerated; in addition, it would be an advantage if a mixture of lower melting-point could be achieved. Kaolinite, which is a very abundant mineral, might prove to be suitable for this type of process, as it can be mixed with salt solutions to form extrudable pastes which can then be fired (Fig. 2).

Natural Soils—Active solutions of high salt and acid content have been mixed with soil to form pastes, which have then been dried and fired at 1,000° C. Preliminary results (Table 3) suggest that the degree of fixation is as good as that achieved by ion-exchange and firing, but much higher loadings have been obtained, and the presence of a large excess of inactive

ions and of acid seems to be without effect. Good results have been obtained with two types of soil, a Lower Greensand containing very little lime and a chalky topsoil with ~20% $CaCO_3$. In the latter case the acid is neutralized on mixing, and there may be a future for this type of soil in treating acid wastes, although the process obviously requires careful control.

Table 3. Fixation of activity on a lower greensand soil.[8] Firing temperature: 1,000° C (8 hrs.).

Method	Solution	Loading meq./g	% Retention on Leaching			
			5N.HNO_3 (3 hrs.)		Distilled Water (1 week)	Sea-water (1 week)
			Cold	Boiling		
Ion-exchange	0.02N.Cs+ *	0.2	> 99	> 99	99.91	99.90
	0.02N. Mixed fission products, pH 5	0.2	98.0	94.8	> 99	> 99
Mixing	0.5N.Cs+ * 3.0N.Fe^{3}+	1.05	97.8	79.9	99.7	99.8
	0.5N.Cs+ * 3.0N.Fe^{3}+ 3.0N.HNO_3	1.95	99.4	94.9	99-100	99-100
	Simulated Waste†	3.5	78.7	52.0	99-100	99-100
	0.1N.Cs+* 20.0N.Zn^{2}+	10.1	99.50	98.78	99.47	99.06

* Tracer-active species.
† Mixed fission-products + inactive contaminants in 3N.HNO_3.
Contaminants: active ions = 60:1 on equivalent basis.

The melting-points of mixtures with soils are again in excess of 1,000° C, the greensand melting at ~1,350° C, and the materials tested so far have been in the form of sintered masses. For economic reasons and for ease of handling it would be an advantage to produce a melt at as low a temperature as possible; this would also minimize the volatilization of activity from the melt. The only serious source of volatile activity at temperatures below 1,000° C is likely to be ruthenium, which under oxidizing conditions volatilizes as RuO_4 at ~150° C. This may be reduced by prior removal of nitric acid, or by carefully-controlled firing in a reducing atmosphere. Further work is necessary to achieve relatively low melting-points and to minimize loss of volatile activity.

A process of this kind offers several advantages over one based on ion exchange. It can be operated with either separated or unseparated wastes, and in the former case the much higher loadings make it possible to concentrate the activity into a smaller bulk whilst fixing it equally well. In principle the process is not limited to ionic wastes in solution, but can be applied to solid wastes, slurries, or active incinerator ashes, provided that conditions are adjusted to maintain the correct proportions of the basic constituents for forming the required melt. As a further possibility, we can envisage a system in which all highly active waste solutions are reduced to very small bulk by evaporation or precipitation; the mixed wastes (solids, slurries, etc.) could then be converted into glasses by adding the required amounts of other materials and melting; fusion might be either a batch process or along the lines of a continuous glass furnace. Methods of this type, although at first sight less amenable to remotely-controlled operation than a column process, are so much more versatile that the effort required for their development is worth while if a disposal programme based on solids is desired. The degree of concentration achieved compared with the original

La Fixation de l'Emanation Radioactive

L'une des méthodes les plus prometteuses pour le traitement des résidus radioactifs est fondée sur la transfromation en solides des liquides rejetés par absorption sur matières siliceuses qui après avoir été cuites ne sont pas filtrées par les eaux naturelles. Les argiles ont été utilisées comme matière absorbante dans une colonne sous les formes de pâtes et de granules pré-agglutinées avec de l'ethyl orthosilicate. Les limitations de cette technique sont discutées particulièrement en ce qui concerne leur capacité.

Une autre méthode est celle qui consiste à incorporer les résidus dans de l'argile ou des sols avec un grand accroissement correspondant de capacité. Le mélange est mis en pâte, fondu ou extrudé, séché puis cuit. Les sols naturels semblent résister à une filtration postérieure d'une manière satisfaisante. Le ruthénium ayant une volatilité faible occasionne toujours certaines difficultés. Les résultats provenant d'une série limitée d'expériences sont cités. A titre d'essai on propose l'utilisation de la chaleur due aux radiations pour une auto-fixation ou au moins un auto-séchage.

Tandis que le système d'échange d'ion est plus directement susceptible d'un contrôle indirect, les problèmes ne sont pas considérés insurmontables, et la plus grande capacité devrait justifier un développement et investissement de capitaux plus grands.

Unterbindung der Verbreitung Radioaktiver Abwässer

Bei den Behandlungen von radioaktiven Abflüssen gibt es eine, die etwas mehr versprechend erscheint, nämlich diejenige, die auf der Umwandlung von flüssigen Abfällen in Feststoffe durch Absorption mittels kieselhaltiger Materialien beruht, die nach dem Brennen nicht durch reines Wasser ausgelaugt werden. Ton ist als Absorptionsmaterial in einer Art Kolonnentechnik benutzt worden und zwar sowohl in der Form von Pasten, als auch in einer körnigen Masse, die zuvor mit Ethylorthosilikat gebunden wird. Die Grenzen dieses Verfahrens werden insbesondere in Hinblick auf seine Aufnahmefähigkeit diskutiert.

Ein anderes Verfahren besteht darin, den Abfall direkt in den Ton oder in erdige Stoffe einzuführen, was entsprechend die Aufnahme erheblich vermehrt. Die Mischung wird in pastenartigem Zustand gegossen oder verpresst, getrocknet und dann gebrannt. Natürliche Bodenarten scheinen nachträglichem Auslaugen ausreichenden Widerstand entgegenzusetzen. Ruthenium bietet immer gewisse Schwierigkeiten wegen seiner geringen Flüchtigkeit. Resultate, die aus einer begrenzten Reihe von Experimenten stammen, werden mitgeteilt. Es werden versuchsweise Vorschläge gemacht, wie man die Wärme, die bei der Strahlung entsteht, für selbsttätige Fixierung oder wenigstens Trocknung ausnutzen kann.

Während an sich das System des Ionenaustausches eher zum Kontrollieren durch Fernsteuerung geeignet ist, sind die Probleme doch nicht als unüberwindlich anzusehen, und die grösserer Aufnahmefähigkeit sollte die grösseren Entwicklungsund Kapitalkosten rechtfertigen.

Fijación del Efluente Radioactivo

Uno de los nuevos sistemas que más prometen para el tratamiento de efluentes radioactivos es el que está basado en la conversión de desperdicios líquidos en sólidos por absorción en materiales silíceos que, después de enhornados, no dejan percolar las aguas naturales. Se han empleado arcillas como material absorbente en una técnica de columna tanto en forma de pasta como en forma de granos previamente ligados con ortosilicato de etilo. Se discuten particularmente las limitaciones de esta técnica en lo que se refiere a capacidad.

Un sistema alternativo es el de incorporar el desperdicio en arcilla o tierras con una capacidad de absorción correspondientemente mayor. La mezcla se convierte en pasta que se moldea o se forma por extrusión, luego se seca y por último se enhorna. Las tierras naturales parecen resistir la ulterior lixivación satisfactoriamente. El rutenio, debido a su baja volatilidad, siempre presenta algunas dificultades. Se citan los resultados obtenidos con una serie limitada de experimentos. Se sugieren algunas ideas para la utilización del calor engendrado por las radiaciones para la autofijación o al menos para el autosecado.

Aun cuando el sistema de intercambio de iones se presta más fácilmente al mando a distancia los problemas que surgen no se consideran insuperables y la mayor absorción debiera justificar las mayores ampliaciones y gastos de instalación.

solution depends upon the maximum loading which can be attained and upon the density of the final material. Neither of the limits for these is at present known, but loadings have been readily attained which correspond to a solid volume equal to the original liquid volume (for concentrated solutions) even without fusion of the solid, and it is almost certain that this can be improved appreciably. Although this type of storage of wastes may not appear practicable for the very large volumes arising from present-day separation processes, it would be highly suitable for wastes arising from homogeneous reactors or from individual laboratories, provided that the required resistance to leaching over long periods can be attained.

Disposal of the Fixed Solid Wastes

Once fixed in the solid form, the most logical course would seem to be to bury the products. As they are highly active, and will remain so for a long time, some form of cooling will be required, either by forced-air ventilation or by immersion under water. Alternatively, they could be buried in the ground, preferably in a medium of low water porosity not associated with water-bearing formations; thick clay strata would be ideal for this purpose.

A solid source of fission products surrounded by a good insulating medium will of course reach and maintain a temperature above that of its surroundings until all the activity has decayed, and the temperatures expected for different nuclides have been calculated for infinite geometry.[11] These are dependent on the loading, half-life, energy of the radiation, and dimensions of the source, but it appears that under suitable conditions it might prove possible to raise the temperature sufficiently by radioactive decay to achieve fixation without the application of external heat. In carrying out such a process of "self-fixation," it would be essential to ensure that the temperature did not fall below that required for efficient fixation over a distance equal to that through which the activity could diffuse during the process. Recent model experiments,[12] in which the heating has been produced by means of a central furnace, show that the temperature falls very considerably within a small distance of the boundary of the heated zone, so that ideally we should aim to produce the required temperature in a short time. This, together with geometrical conditions, requires using mainly the medium-life members (Zr, Ce, Ru) to produce the heating, rather than the less efficient, longer-lived Cs and Sr. This indicates a further advantage of a batch mixing process without separation, as opposed to one based on ion exchange.

The idea of self-fixation is, however, still in its infancy. Any process for fixation of wastes in solid form will certainly be based initially on external heating with prolonged leaching tests under a variety of conditions to ensure that the amount of activity removable is within the accepted tolerance limits. Self-fixation is a further stage in development which could only be advocated after the most stringent tests to ensure its success.

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The Hanover Fair

DIRECT services from all the major cities of Europe ensure that visitors to Hanover during the annual Fair arrive with a minimum of delay. The city itself is fully geared to cope with the enormous influx of visitors and although war damage has left some deficiency in hotel accommodation, this is rapidly being rectified with typical German industry. A special department, run by the Fair authorities, arranges private lodgings for visitors unable to book an hotel. The Fair is situated about 5 miles outside the city and has parking facilities for over 4,000 cars, whilst direct bus and tram services are available to the main entrance.

The site of the Fair, covering many acres, is provided with ten permanent buildings, each comparable in size to Earls Court. A further four buildings of wood and canvas house the remaining small exhibits, and acres of hard standings are used for exhibiting building and construction machinery, locomotives, generators, etc. Apart from these stands, several of the larger concerns own permanent buildings of their own design which are modified from year to year to suit their requirements. The Fair is very well served with information bureaux, travel agents and National Export and Board of Trade representatives and full postal facilities are available. A staff of stenographers and interpreters is at the call of those who wish to keep in touch with offices and customers. A special arrangement with the customs authorities enables exhibitors to ship equipment direct to the Fair without examination at the German border. The customs officers visit the individual stands as cases are delivered so that delay is kept to a minimum. A remarkably comprehensive catalogue is provided, indexed both under types of equipment shown and names of exhibitors, together with detailed plans of the various halls. The necessity of such a catalogue is made obvious when it is realized that to inspect every exhibit, a visitor must cover a little over 40 miles if he takes the shortest possible route.

At this year's Fair nucleonic equipment for research work was shown by Sunvic Controls Ltd., and Isotope Developments Ltd., great interest being shown in the Sunvic multichannel pulse height analyser on show for the first time at Hanover. Industrial uses for isotopes, featured by I.D.L., aroused considerable interest as so far, very little beyond standard gauges appears to be available from Continental suppliers. Frieseke and Hoepfner and Electro-Special showed equipment manufactured in Germany including coincidence counting equipment both for scintillation and geiger counters. A photomultiplier manufactured by Fernsch in Germany is now in common use for scintillation counting equipment. Tracerlab, Landis and Gyr, Bruel and Kjaer, exhibited various types of counting equipment and Herfurth GMBH of Hamburg showed a range of survey meters for Civil Defence use.

A large number of really serious inquiries for the nucleonic equipment were received from many countries, including the Iron Curtain areas. Orders were in fact placed with one English manufacturer by a state buying concern from Prague.

From a trade point of view, the truly international nature of this Fair, both of exhibitors and visitors, makes it probably the most cosmopolitan exhibition at present held in Europe.

The A.M.F.-Mitchell Reactor

The Anglo-American team formed by Mitchell Engineering Ltd. of England and A.M.F. of the U.S.A. have concluded that the boiling-water reactor feeding a heat exchanger is the most economical and safe system for small electrical or process steam generating plant.

by
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Senior Design Engineer, Mitchell Engineering Ltd.

ECONOMY of operation and safety were the two major criteria influencing Mitchell Engineering Ltd. of London and Peterborough and A.M.F. Atomics Inc. of New York in their design of nuclear plant, for use in areas requiring small or medium sized electrical generating or steam producing plant for local communities and industrial establishments. Costs had to be comparable with those obtaining in districts favoured with a cheap supply of coal, oil, or other fossil fuel. In the course of their initial studies gas cooled, liquid metal cooled, pressurized water, and boiling water reactors were investigated, the last named finally being adopted. Experience of this type of reactor gained in the U.S., notably at the Argonne National Laboratory, has enabled firm design plans to be drawn up.

A fairly standard pressure of 650 p.s.i. is maintained for the steam supply to the turbine or process plant but the pressure can be varied if this is required—to suit existing plant for example.

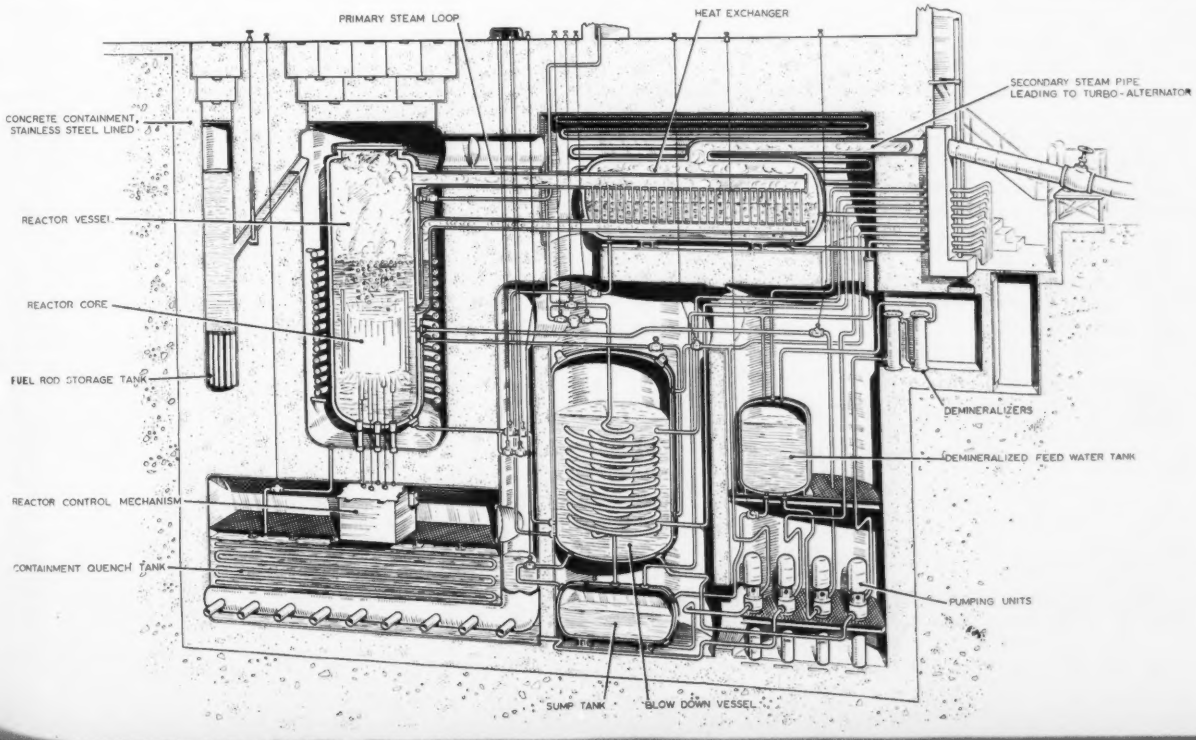
Most of the fuel elements in the core are of natural uranium in thin plate form and canned in zirconium alloy. The remaining elements which "spike" the core are of a fuel enriched with U^{235} which is also canned in zirconium. The use of natural uranium throughout and heavy water as moderator was ruled out because of expense.

The reactor control system, comprising ten or eleven rods a number of which are employed for shut-off and the remainder for fine control, maintains the steam in the reactor vessel and primary loop at a constant pressure. Heat is conveyed from the core by the natural circulation of the steam and water mixture through the uranium fuel elements. A riser pipe is fitted above the core to ensure the required speed of circulation.

Steam from the reactor is delivered into the upper part of the reactor vessel thence through a large pipe to the tubeside elements in the heat exchanger. The water of the secondary non-radioactive water is in contact with the external surface of these elements. The primary loop steam condenses into water and then flows back by gravity to the reactor vessel. The circuit is so designed that a few feet of hydraulic head are sufficient to overcome the frictional resistance of the pipes and heat transfer elements and no pump is needed. Under normal conditions steam in the reactor vessel—conservatively designed to withstand an operating pressure of 1,000 p.s.i.—is produced at 534°F and 900 p.s.i. Water circulation in the core corresponds to a flow of 12,000,000 lb./hr. and a steam flow of 300,000 lb./hr. to the heat exchanger is envisaged.

The steam produced in the heat exchanger (at about 650 p.s.i. and 497°F) is piped to the turbo-generating plant or is led through a separately fired superheater if a high degree of superheat is needed. The steam output from the heat exchanger is automatically controlled by the turbine or process steam demand, as measured by the flow and pressure in the turbine steam main. An increased flow transmits a proportional impulse to the heat exchanger feed inlet control valve and with a greater quantity of water being admitted, the water level in the vessel rises. The amount of primary loop surface in contact with the feed water is thereby increased and steam is produced at a proportionately increased rate.

The turbine steam-main pressure is used as an anticipatory signal to the feed controller and this signal is also transmitted to the reactor fuel rod controls to initiate the main reactor control, actuated primarily by the steam pressure in the reactor vessel. This pressure will remain practically constant at a steady heat output, but if a greater quantity of heat is



absorbed by the secondary circuit, the steam flow from the reactor vessel will increase and the pressure will tend to fall. A proportional impulse will cause the control rods to withdraw from the reactor core. The pressure in the reactor vessel will return to normal and will give the increased rate of heat output required. Whilst the system can meet rapid variations in steam demand, the effects on the reactor are largely cushioned by the heat exchanger.

The vessel of the A.M.F.-Mitchell reactor is to be fitted with a number of safety devices. These would come into operation in the following sequence:

1. If pressure should rise 5% above normal operating conditions, the reactor control rods would be inserted automatically into the shut-down position. If pressure should continue to rise then—
2. A spring-loaded blow-down valve would automatically open and lower the water level to a height just below the core riser pipe. Circulation of water through the fuel elements would be halted and the channels through the core would become full of steam. This would reduce reactivity and the reactor heat output decrease considerably. If this measure should fail then—
3. A solution of boric acid (a strongly neutron absorbing medium) would be injected into the reactor water by a helium pressurizing system. This equipment would come into operation at a setting pressure of, say, 10 p.s.i. above the spring-loaded blow-down.
4. As a further precaution, a steam safety valve is provided. This would lift if the pressure still continued to rise and would release steam from the upper portion of the reactor vessel into the containment space. The steam would not be discharged to the outside atmosphere.

If, as an ultimate possibility, the reactor vessel should rupture, the design of the reactor caters for the safety of the operating personnel. The containment area is of sufficient volume to hold the steam and water escaping from the rupture. The concrete structure has been designed to withstand a momentary shock of 50-60 lb. per sq. in. and a subsequent steady fall of pressure spread over possibly a few minutes. In this period the released steam would be condensed in the containment quench tank and prevent radioactive steam or liquid escaping into the outside atmosphere.

In using light water as a moderator, it is essential that the water contained in the closed cycle be maintained in as pure a condition as possible. This is achieved by circulating a small but steady flow of water from the reactor vessel through porous stainless-steel filters and an ion-exchange column into a feed tank and then through a small capacity feed pump into the reactor vessel.

Any loss of water in the system is regained by demineralized water fed from an external storage tank through a float-controlled valve on the feed tank.

Radioactive drain water from the varicus pump glands, valve stems, etc., is handled by special arrangements including drain pockets with pipes leading from them to a sump tank situated low in the containment area. When this tank is near capacity a magnetic float switch starts the sump tank dump pump. The drain water is then discharged into a large underground storage tank located outside the containment area. The drain water is kept in this tank for six to twelve months until radioactivity has fallen to a safe level.

It is necessary to replace some of the uranium fuel elements in the reactor core every twelve to fifteen months if the plant has been working at a fairly high load factor during that period. Specially trained engineers, provided by the two companies, visit a plant for a short time to carry out the refuelling operation which is done as follows:

(a) Demineralized water from a large storage tank situated outside the containment area is flooded into the reactor vessel shield tank (i.e., the space round the reactor vessel).
(b) The concrete blocks above the reactor vessel are removed by the overhead crane in the fuel handling bay and a further quantity of water is run into the shield tank to bring the level almost up to the operating floor.
(c) A specially designed type of extension gear is used to loosen the securing bolts and access door in the top of the reactor vessel and a remote-operated tool lifts out the fuel elements, one at a time, placing them in the storage tank.
(d) The new elements are then inserted into the core, the access door replaced, and the shield tank drained.

The used fuel elements are left in the storage tank from six to twelve months to "cool off."

Special attention has been given to the starting up of the reactor. It can be started, of course, in cold conditions but it is preferable to bring it into operation when the metal temperatures throughout the system are near normal working conditions. In the A.M.F.-Mitchell boiling water reactor a special system has been developed so that the reactor vessel, the heat exchanger, and the steam mains can be gradually warmed through to bring them up almost to normal working pressure and temperature. The turbo alternator can also be warmed through and run up to synchronous speeds if necessary before the reactor is brought into operation.

Le Réacteur A.M.F.-Mitchell

Les dessins de petites stations génératrices et d'installations génératrices de vapeur par Mitchell Engineering Ltd. de Londres et de Peterborough et par A.M.F. Atomics de New York sont fondés sur les principes du réacteur à l'eau bouillante qu'on a choisi en partie à cause d'économie et en partie à cause de sa sécurité inhérente. Le récipient du réacteur, qui contient un mélange d'éléments combustibles d'uranium naturel et d'uranium enrichi qui sont mis en boîtes d'alliage der zirconium, est construit pour opérer à une temperature de 534°F, et sous une pression de 900 p.s.i. (63,3 kg/cm²). La circulation de l'eau qui compte seulement sur le cycle thermique est à peu près 100,000 kg par minute, avec un rendement de vapeur de 2,400 kg par minute. La vapeur du noyau de réacteur passe à un échangeur thermique d'où la vapeur est produite sous une pression de 650 p.s.i. 457 kg/cm² et à 497°F et de là conduite à une installation génératrice.

Das Kernkraftwerk der A.M.F.-Mitchell

Konstruktionen kleiner Kraftwerke und dampferzeugender Anlagen der Mitchell Engineering Ltd., London und Peterborough, und der A.M.F. Atomics Inc., New York, beruhen auf den Grundsätzen des Heisswasser Reaktors, den man gewählt hatte, einmal aus Gründen der Wirtschaftlichkeit, dann wegen der damit verbundenen Sicherheit. Der Reaktorblock, der eine Mischung von natürlichen und angereicherten Uran-Brennstoffelementen enthält, die in einer Zirkonlegierung eingekapselt sind, ist entworfen worden für eine Dampftemperatur von 534°F (279°C) und einen Druck von 900 p.s.i. (63,3 kg/cm².). Der Wasserumlauf, der auf Wärmewirkung beruht, hat die Grössenordnung von 100,000 kg pro Minute bei einer Dampferzeugung von 2400 kg pro Minute. 10 oder 11 Stäbe werden zum Abstellen 2400kg pro Minute. Der Dampf geht von dem inneren Reaktorenblock zum Wärmeaustauscher, in welchem Dampf mit einem Druck von 650 p.s.i. (45,7 kg/cm.²) bei 497°F (258°C) erzeugt wird, und geht dann von dort zum Kraftwerk.

El Reactor A.M.F.-Mitchell

Los diseños de pequeñas centrales generadoras y plantas para la producción de vapor de la Mitchell Engineering Ltd., de Londres y Peterborough y de la A.M.F. Atomics Inc., de Nueva York se basan en los principios del reactor al agua hirviente, el que fué elegido, en parte, por razones de economía y, en parte, por su inherente seguridad. El recipiente reactor conteniendo una mezcla de elementos combustibles de uranio natural y enriquecido envasados en una aleación de zirconio, está diseñado para poder operar con una temperatura de vapor de 534°F a una presión de 900 libras por pulgada cuadrada (61,5 atmósferas). La circulación de agua, a base de ciclaje térmico únicamente, es del orden de 100.000 kilógramos por minuto, con una producción de vapor de 2.400 kilógramos por minuto. El vapor desde el núcleo del reactor pasa a un cambiador de calor, en el que se produce vapor a una presión de 650 libras por pulgada cuadrada (44 atmósferas aproximadamente) a 490°F, y de allí va a la planta generadora.

Properties of Graphite

Graphite is one of the most inert materials chemically. Examination of the structure shows desirable characteristics for lubrication or constructional work. The mechanical, thermal and electrical properties are discussed in relation to changes of temperature. Purity is a function of raw materials.

by
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THE use of graphite as a moderator and reflector in nuclear reactors has intensified interest in the structure and the mechanical and chemical properties of this material. In the past it has been largely through the use of graphite, and graphite dispersions for lubrication, that the salient properties have been discussed, the use of graphite for electric furnaces, electrochemical processes and for certain chemical engineering projects having received narrower, more specialized treatment. From a position of being a specialized material graphite is now taking its place alongside the more important alloys and other raw materials that go to make up the sinews of modern industry.

Grey-black in colour, graphite is one of the softest minerals, occupying a position of No. 1 on Mohs' scale of hardness. More will be said later of how this softness is reconciled with the apparent mechanical strength of massive electric furnace graphite. The material is, for all practical purposes, chemically inert, although it will dissolve in a mixture of nitric and sulphuric acid, which is the basis of the Brodie reaction. Its resistance to attack by acids and alkalis, and its comparative heat resistance give the material wide uses in industry. Among the acids to which it is resistant are hydrofluoric, formic, nitric (up to 30%) and sulphuric (up to 96% cold and to 76%, boiling). It withstands boiling caustic soda and ammonium hydroxide, as well as trichlorethylene, sodium hypochlorite and other industrial solutions. The density, calculated from consideration of the atomic structure is 2.25 and by X-ray analysis, 2.27, but a value of 2.2 is generally accepted. The apparent density of a piece of electric furnace graphite would lie nearer to 1.5, owing to porosity, whilst in the powder form the apparent density would depend on the closeness of packing of the powder particles which, in turn, depends, principally, on powder size.

Graphite is the stable allotrope of diamond and carbon, and has an atomic weight of 12.010, an atomic number of 6 and an atomic volume of 5.41 c.c./g atom, compared with 6.7-8.0 for carbon. Although graphite is made up of carbon atoms arranged as in Fig. 1 the contrasting disorder of the layer planes in so-called amorphous carbon, or microcrystalline graphite, as it is sometimes described, suggests that the synonym of "carbon" for "graphite" is not technically accurate, and should be avoided. It is equally inappropriate to refer to diamond as "a carbon."

Some Structure Aspects

Referring to Fig. 1 the sheets of atoms arranged as a hexagonal network, are 1.42Å apart. A typical X-ray diffraction spectrum for graphite is shown in Fig. 2 the 002 line representing the carbon sheets being prominent. Whilst the distance between the sheets is subject to small variations the spacing between the atoms in the sheets is generally assumed to be invariable, except perhaps in the case of edge atoms in the layer planes, to which Bradburn, Coulson and Rushbrooke (1948) have paid attention. This leads to a variation in the mean mobile binding energy per carbon atom from 1.3333 to 1.5761, according to the position of the atoms in the sheet. In discussing the structure of a so-called pure graphite, as made in the electric furnace, reference should be made to the possibilities of hydrogen saturating the edge valencies of the

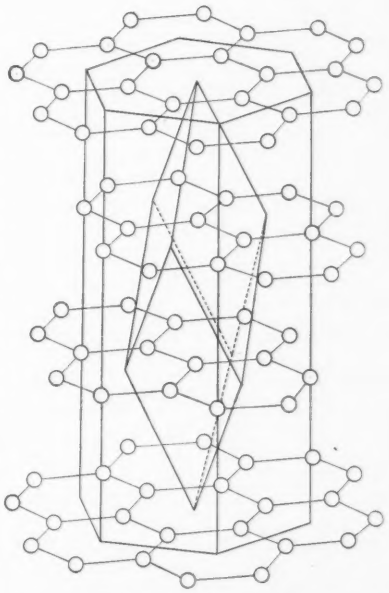


Fig. 1. Illustrating the arrangement of carbon atoms in graphite.

sheets. The three investigators quoted above also draw attention to the possibility of acetylation of these edge atoms.

The crystallite size which influences the mechanical properties of the bulk material may be defined, in broad terms, as the size over which a continuous and regular structure is observed. Compared with graphite made electrothermally, natural graphite has a large crystallite size, the continuous extension of the carbon sheets usually exceeding 1,000Å, whereas in the electrothermal product the extension is about 500Å or less, depending on the mode of manufacture. A poorly graphitized carbon may show a crystallite dimension of around 100Å.

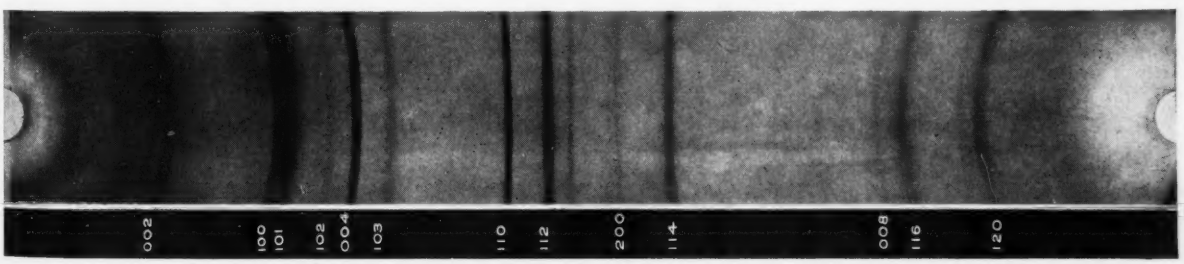


Fig. 2. A typical X-ray diffraction spectrum for graphite, the 002 line (extreme left) representing the carbon sheets being prominent.

whilst synthesized graphites are known with a crystallite size exceeding the most platey type of natural graphite. For lubrication purposes a large crystallite size is preferred to give unctuousness but where mechanical properties are paramount in massive graphite a moderately small dimension can be desirable.

The spacing between the carbon sheets in the structure of graphite is 3.35Å but if one size-reduces the material by grinding, there is an accompanying modification of the sheet spacing which may, on occasions, go up to 3.4Å. A disorder occurs in the lattice and this has been measured quantitatively by G. E. Bacon using X-ray diffraction in which the probability p of a "mistake" in the lattice is related to the amount of size reduction. The effect is shown in Fig. 3 together with the figures for "height" and "length" changes of the crystallites.

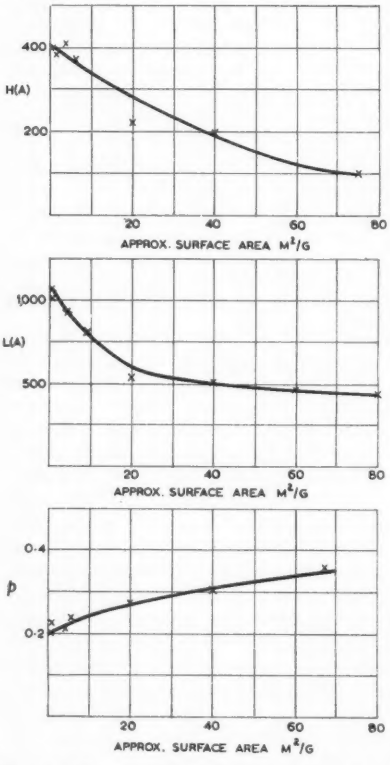


Fig. 3. Change of structure of electric-furnace graphite with decreasing particle size.

From considerations of the lattice dimensions one is led to the subject of electronic structure. A certain amount is known about this, but more secure information is needed to yield a firm picture. The relatively great distance between the sheets of atoms gives rise to a weakness of bond between the sheets, or as it is usually stated, there is a weak fourth valency which is normal to the layer plane. This gives rise to a mobile or π electron between the sheets, which it is thought, is the reason for the electrical conducting properties of graphite. Studies have been made of the energy levels existing in this domain of the lattice, but it is not proposed to deal with this intricate aspect of the structure.

Mechanical Properties

If one examines a block of pure electrothermal graphite it has a cold feel and a slightly metallic ring when struck. This is in complete contrast to the character of the material in powder form. One can only surmise, from related data, about the make-up of such a block. One thing is evident: the crystals of graphite within the block are arranged with random orientation. It is possible, even probable, that the mass is made up of packets of orientated crystallites of graphite which are disorientated. That is why it has been said earlier that the smaller the crystallite size the "harder" the graphite. If the platelets were orientated throughout the block one would expect a pronounced anisotropy in mechanical and electrical properties whereas in practice the differences in electrical conductivity and strength in perpendicular directions bear no resemblance to those expected from a consideration of the anisotropy of a crystal. In the crystal the electrical and thermal conductivity is of quite a different order in the plane of the carbon sheets and compared with that normal to the plane. This leads one to the concept of the make-up of electrothermal graphite shown schematically in Fig. 4. The crystallite size and the disorder of the crystallite within the

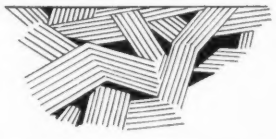


Fig. 4. Schematic make-up of electrothermal graphite: the black parts represent pores.

mass will give a piece of electric furnace graphite an appearance of hardness which seems to conflict with its position as No. 1 on Mohs' scale. The real softness comes from the ease of cleavage of the platelets when rubbed. The graphite crystal has very little mechanical strength in the direction of the carbon sheets, which helps to explain why it is a lubricant. Normal to the cleavage or slip planes, however, it offers a measure of mechanical strength, so that if the platelets are so interlocked in a mass as to prevent cleavage or slip the weakness in shear is not apparent. Consequently the mass appears to have a higher hardness than warranted by its position on Mohs' scale. Massive graphite will fracture easily, owing to the presence of the weak shear planes, there being no bonding between those planes. It is also probable that the lack of bonding between the packets of platelets in the mass will also present a structural weakness.

The following data summarizes the mechanical properties of graphite made in the electric furnace for electrode purposes. This can be taken as a good guide to the range of properties to be expected from a graphite made by the conventional Acheson process from petroleum coke.

Tensile strength	:	500-1,000 lb./sq. in. up to 2,000°C
Compressive strength	:	1,500-3,000 lb./sq. in.
Modulus of elasticity	:	0.8 to 1.5 x 10^{-6} lb./sq. in.
Volume compressibility	:	2-4 x 10^{-6} cm²/kg
Density	:	1.5 (approx.)

Graphite is no exception in showing a loss of mechanical strength at high temperatures, but in this respect it shows a considerable improvement over the highest melting point alloys. The relation of tensile properties to tem-

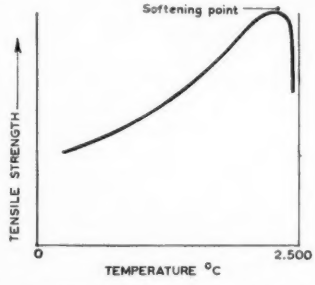


Fig. 5. Generalized picture of change of tensile properties with temperature.

perature is shown in Fig. 5 from which it will be seen that there is a softening point in the region of 2,500°C.

In the more conventional reactors such as the gas-cooled graphite-moderated designs the blocks of graphite have merely to support each other, so that there is no particularly stringent requirement on such characteristics as crushing strength. In general electrothermal graphite of the above range of mechanical properties is machinable, an important feature. In point of fact electrothermal graphite made today is frequently threaded and machined to close tolerances, like a metal. Where graphite is used in later industrial reactors it may have to fulfil certain structural needs, but the indications are that there should be no difficulty in this direction.

Continuous irradiation leads to an increased disorganization of the lattice and a consequent change of the physical properties of graphite. It is hoped that more data on this aspect will be published in the near future.

The thermal properties of graphite assume considerable importance in this class of work. The linear coefficient of

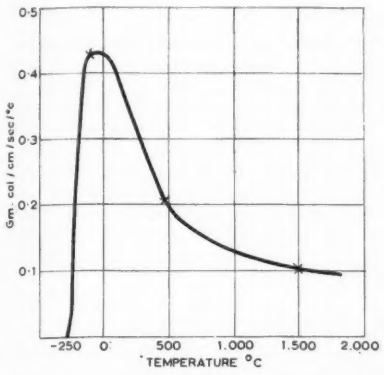


Fig. 6. Heat conductivity of electrothermal graphite.

expansion between 0° and 1,000°C lies in the vicinity of 20−40 x 10^{-7}, for massive polycrystalline material. Walker, McKistry and Wright found that the expansion between −196°C and 1,118°C along an axis normal to the carbon sheets (i.e. *c* axis) is 28 x 10^{-6}, and is independent of whether the atmosphere is oxygen, nitrogen, argon or carbon dioxide. This agrees well with an X-ray computation of 26.7 x 10^{-6} made by Backhurst. It will be noted that the expansion coefficient of the material is low compared with metals. Being anisotropic the graphite has a different thermal expansion along the *c* axis of the crystal from the *a* axis.

A great deal of work on the heat conductivity of graphite has been reported. As one might expect, heat is conducted more readily along the carbon sheets than in a direction perpendicular to the sheets. The maximum conductivity is achieved at sub-zero temperatures and falls steadily with increasing temperature up to 2,000°C. The general shape of the curve of conductivity versus temperature is shown in Fig. 6.

Electrical Conductivity

The resistivity of electrothermal graphite is related to the initial raw materials from which it is made, the temperature and time of graphitization and other factors. Generally speaking graphite offers a resistivity which puts it in the class of a conductor. For that reason it is used widely in the form of colloidal dispersions to form conducting coatings on electronic devices of various kinds, in addition to the employment of the massive form for the electrodes in resistance furnaces. The massive form of the material of apparent density of 1.5 can be expected to show a resistivity in the region of 15 x 10^{-4} ohm-cm. The resistivity varies with density as one might anticipate. Graphite films formed with colloidal dispersions will offers resistivities of from a few ohms per unit area up to megohms depending on the thickness of the film and the condition of the surface on which the graphite rests.

Of prime importance in nuclear work are the extent, and nature, of the impurities in graphite. These will of course, be related to the original graphitizing stock, and for that reason a coke with low ash is usually selected for the raw material to be graphitized. It is difficult to secure any raw material in nature free from iron, and petroleum coke is no exception. Oxides of iron will, therefore predominate, along with a small amount of silicon in combined form, such as silicon carbide. The following is a typical analysis of a high quality electrothermal graphite:

Carbon	99.900
Iron	0.050
Copper	0.002
Manganese ...	0.001
Sodium	0.001
Calcium	0.005
Silicon	0.020
Vanadium	0.005
Sundry	0.016

It should be emphasized that there is no such thing as a characteristic impurity range in graphites made in the electric furnace. Most initial impurities are volatilized at the temperature of graphitization (around 2,800°C) but traces condense back on the furnace charge when the latter is cooled. Thus, silicon and iron are vaporized, when not combined with the carbon in the coke. There are certain classes of impurities which are undesirable in reactor work, but an attempt is made to keep all impurities at a minimum. Where graphite is used as a moderator, control is exercised over the impurities by selection of raw materials for graphitizing.

La Propriétes Mécanique du Graphite

L'emploi du graphite comme modérateur a créé un intérêt dans les qualités mécaniques de la substance qui au préalable avait été presque exclusivement limité aux qualités lubrifiantes. Le graphite est l'une des substances les plus inertes chimiquement, et aussi l'un des minéraux les plus mous, qui a une densité de 2,2 et une densité apparente de 1,5 dependante de la porosité. Dans la discussion de quelques aspects de la structure on donne des chiffres pour l'espacement des couches d'atomes et pour la hauteur et la longueur des cristallites. Le chiffre moyen de l'espacement est 1,35 angstroms tandis que la grandeur de la cristallite peut varier de 100 à 1000 angstroms. Le meulage mécanique de la substance modifie tous ces chiffres.

Plus la cristallite est petite, plus le graphite est dur, ce qui est un trait désirable au point de vue de construction mais pas pour la lubrification. Le graphite surpasse la plupart des alliages en ce qui concerne des qualités mécaniques à des températures élevées. Il existe peu de publications sur le changement de dimension sous l'infuence de l'irradiation prolongée. On donne des chiffres pour la conductivité thermale à des temperatures diverses et pour la conductivité électrique. La pureté est de toute première importance pour les réacteurs et bien que la plupart des impuretés se vaporisent à la temperature de graphitisation (2800°C), des matières premières pures sont très necessaires.

Mechanische Eigenshaften des Graphits

Die Verwendung von Graphit als Bremsstoff hat das Interesse an den mechnischen Eigenschaften dieses Materials geweckt, das bisher fast ausschliesslich auf sein Verhalten in der Anwendung als Schmiermittel gerichtet war. Graphit ist einer der chemisch trägsten Stoffe und ferner eines der weichsten Mineralien mit einer Dichte von 2,2 und einer anscheinenden Dichte von 1,5 die von der Porosität abhängt. In der Diskussion einiger Punkte der Struktur werden Zahlen für den Abstand der Atomschichten und der Höhe und Länge der Kristallpartikel gegeben. Die mittlere Zahl für den Abstand ist 1,35 Angströms, während die Grösse der Kristallpartikel zwischen 100 und 1000 Angströms variert. Mechnisches Zermahlen des Materials verändert alle diese Zahlen.

Je kleiner die Grösse der Krystallpartikel ist, desto härter ist der Graphit, was für den Aufbau von Konstruktionen eine sehr erwünsche Eigenschaft ist, wenn auch nicht für die Verwendung als Schmiermittel. Graphit bringt eine bedeutende Verbesserung der mechanischen Eigenschaften der meisten Legierungen bei höheren Temperaturen. Es werden Zahlen über die Wäremleitfähigkeit bei verschiedenen Temperaturen gegeben, ferner über die elektrische Bedeutung in der Verwendung von Graphit Kernkraftwerken, und wenn auch die meisten Verunreinigungen bei der Graphitisierungstemperatur von 2800° C verdampfen werden, so sind doch reine Rohmaterialien äusserst notwendig.

Las Propiedades Mecánicas del Grafito

El uso del grafito como un moderador ha creado interés en las propiedades mecánicas del material que anteriormente había sido casi exclusivamente limitado a su comportamiento en aplicaciones relacionadas con la lubrificación. Químicamente el grafito es uno de los materiales más inertes, y también uno de los minerales más blandos con una densidad de 2,2 y una aparente densidad de 1,5 según la porosidad de él. En la discusión sobre algunos aspectos de la estructura, se dan cifras para el espaciado de las láminas de átomos y para la altura y la largura de los cristalitas. La cifra media para el espaciado es de 1,35 angstromos, mientras que el tamaño de los cristalitas pueden variar entre 100 y 1000 angstromos. La trituración mecánica del material modifica todas estas cifras.

Cuanto más pequeño el tamaño del cristalita, más duro es el grafito, una característica deseable para trabajo de construcción, aunque no así para lubrificación. El grafito muestra gran mejoría sobre la mayoría de las aleaciones en propiedades mecánicas a elevadas temperaturas. Poco se ha publicado sobre el cambio de dimensión bajo el efecto de prolongada irradiación. Las cifras se dan para la impurezos se vaporizarián a una temperaturas y para conductividad eléctrica. La pureza es de primordial importancia en trabajos con reactores y, aunque las impurezas se vaporizarán a una temperatura de grafitización de 2800°C, son del todo necesarias materias primas puras.

World News

INTERNATIONAL

U.N.E.S.C.O. has undertaken to assist Greece in the setting up of a body to handle atomic energy matters by granting two research scholarships to Greek scientists. At the same time a reputable physicist will be sent to Greece for a period of one year. The plans also make provision for financial assistance to the Greek Nuclear Research Service for the promotion of social studies and education.

Air and Sea Pollution. An international commission on May 15 agreed to recommend the United Nations to take steps to prevent air pollution as a result of nuclear explosions. The draft article also calls for the setting up of regulations to prevent pollution of the sea by radioactive waste disposal. The article, however, is more comprehensive in nature and takes into account such matters as oil pollution.

French Dissatisfaction. Sole dissentient in the vote taken on May 12 by the Common Assembly of the European Coal and Steel Pool on draft plans for Euratom was the representative from France, Monsieur Debre, who is quoted as stating that "this remote imperialism from Cairo threatens to destroy all our efforts towards a happier future for our people." The discussions had been largely confined to the political aspects of the proposed collaboration.

Kjeller reactor power increased. Power of the nuclear reactor at Kjeller, near Oslo, run by the Norwegian and Dutch atomic institutes, is to be increased from 350 to 800 kW. This forms part of the programme for increasing radio-isotope production and for increasing facilities for nuclear engineering research.

BRITAIN

Scottish Power Station. It is probable that the number of contracts for graphite-moderated, gas-cooled reactors to be awarded in 1957 will be increased from two to three. The third reactor is likely to be commissioned by the South of Scotland Electricity Board and preliminary plans site the station near Ardrossan on the Firth of Clyde. The Board is known to have been considering proposals for some time and an official announcement is expected shortly.

Calder Hall reactor critical. Loading of uranium into the first of the reactors at Calder Hall began on April 16 and continued until May 22 on which date the pile diverged. The reactor will operate at zero power for some weeks whilst flux and radiation measurements are taken and control and ancillary gear is tested. Operations are comfortably ahead of schedule and will allow a full programme of checks to be made as each section of the plant is commissioned.

Diploma in Technology. The National Council for Technology Awards is to grant a diploma in technology which will be equivalent in standard to that of an honours degree at a British university. The chairman of the awards committee, Lord Hives, has stated that the purpose of the award was to increase the number of high grade technologists and to create a high standard of teaching.

SUSPOP. The United Kingdom has supplied a quantity of enriched uranium to Holland for the building of a research reactor for the development of nuclear power stations. The initial system investigated has been christened Suspop and is a homogeneous slurry system (suspension power reactor). Prominent in the basic design of this system is Dr. Gerald Went. Agreement for the sale was concluded in March.

Labour Agreement. At the discussions renewed on May 3 after a fortnight's consideration an agreement was reached between the A.E.A. and the trade unions on fixed standard rates of pay and fixed conditions of work for workers in A.E.A. establishments. Although there is still a certain amount of internal friction on the question of skilled and unskilled jobs, the new agreement is likely to stand.

Sir Edwin Plowden, who left on May 6 for a fortnight's tour of the United States, has visited a number of the U.S. atomic energy establishments. Immediately on his arrival he visited the research laboratory of Westinghouse Corporation in Pittsburgh, followed by a tour of the power reactor under construction at Shippingport, Pa. The following day was spent on a tour of the Argonne National Laboratory. Since then Sir Edwin has had a number of top level talks with U.S. scientists and the President. Reports that one of the main topics of conversation was the release of information on the thermo-nuclear reaction have been denied but it is probable that the subject came under review during the declassification discussions with Sir John Cockcroft at the end of April.

The first two issues of *Nuclear Engineering* have created a considerable amount of interest both at home and abroad. A wide distribution has been made to newsagents and bookstalls but it is understood that no copies remain unsold. It is suggested that regular readers would be well advised to place a standing-order with the publishers or their local bookstall and that overseas readers should apply through our overseas subscription agents. Full details of these agents will be found on advertisement pages 37 and 38.

AUSTRALIA

Uranium Sales. In a statement to the House of Representatives recently, Mr. Howard Beale, Minister of Supply, stated that the sale of uranium was bringing in a substantial profit. He added that the loan made by the Combined Development Agency would soon be repaid and the plant would be free of liabilities. Chairman of the Atomic Energy Commission, Sir Jack Stevens, left for the United States on May 10 for talks with Mr. Strauss and Sir Edwin Plowden.

CANADA

Uranium Discoveries. The president of the Anglo-Barrington mine, Mr. L. R. Jackson, has reported an impressive discovery of uranium in north Saskatchewan in the Lake Higginson area, 140 miles east of Uranium City. In a series of diamond drilling operations discoveries were made indicating deposits totalling 200,000 tons containing more than 2 lb./ton uranium. This figure is considered to be conservative. The company is a subsidiary of the Western Selection and Development Company of London.

CHILE

Eleven deposits of uranium have been discovered in the northern part of Chile according to an announcement by the Ministry of Mining. The National Development Corporation, the Mining Development Bank and the National Smelter Enterprise are forming a company with a capital of 60 million pesos to exploit these finds and to continue prospecting.

Under the auspices of the British Council a course has been given on radiation chemistry and radioactive isotope applications at Concepcion University. Equipment was supplied by a number of British manufacturers and the course was conducted by Professor Maddock of Cambridge.

CHINA

Reactor for China. Following the statement by the Minister of Electric Power and Industry, Mr. Lieu Lan Po, on April 21 in Peking that China was to have nuclear power stations and to begin an all-out effort to improve the power industry, Moscow radio announced three days later that Soviet scientists and engineers would build a 60-MW reactor in China. Agreement for this was made last December when the two countries signed a scientific and technical co-operation agreement.

CZECHOSLOVAKIA

Comprehensive plans for the exploitation of atomic energy were announced in Prague on May 3. Included in the country's second five-year plan is a 150,000 kW experimental nuclear power station which is to be in operation before 1961. The power station is to serve as a pilot plant model for further stations to be built between 1961-1966. At the same time plans have been laid for factories to undertake the processing of uranium and the production of heavy water.

FORMOSA

Nuclear Power Plant. Mr. Kaing Piao, minister of economic affairs for the Chinese National Government, has announced that negotiations are in hand with the United States for the setting up of a small nuclear power plant to generate approximately 11½ MW. It is understood that the Government is more interested in the generation of electricity than in research and development in the atomic energy field.

GERMANY

Germany to Buy U.S. Reactors. The Minister for Atomic Affairs, Herr Straus, left for the United States on May 10 to discuss the purchase of complete nuclear research reactors. It is understood that two reactors are being sought for Munich and Hamburg but that others will come under discussion. Following his visit to the United States Herr Straus is to come to Britain at the invitation of the Government for discussions on an Anglo-German agreement on atomic energy. It will be remembered that Sir John Cockcroft paid a visit to Western Germany last year during which tentative plans for collaboration were discussed. However, Herr Straus is quoted as stating that he is planning to spend $100 million in the United States on fuel and complete plants.

INDIA

An agreement with Canada for the establishment of a nuclear laboratory was signed on April 28. Research facilities and an experimental reactor similar to the Canadian NRX will be set up near Bombay at Trombay at a total cost of £5¼ million. 50% of the cost of this project will be borne by Canada under the Colombo plan and work will be carried out by the Shawinigan Engineering Co. India has undertaken to make research facilities available to other countries in S.E. Asia once the establishment has been completed early in 1958, when full operational responsibility will be passed to the Government. Mr. Nehru has indicated that although initially work will be concentrated on radio-isotope applications, this is the first step in a nuclear power programme.

ITALY

CP 5-type Reactor Ordered. An international committee for nuclear research has placed a contract with A.C.E. Industries Incorporated, New York, for the supply of a nuclear research reactor on the lines of CP 5—that is, with enriched uranium as fuel and heavy water as moderator and coolant. The power level will be rated at about 5 MW and the reactor will be used for general research and for the production of radio-isotopes.

JAPAN

Graphite from Coal. It is reported that a government research scientist has discovered a method of producing graphite from coal. If mass-production can be applied to the process it is claimed that the graphite could be made for about two-thirds of the prevailing international price.

Uranium Ore. A considerable quantity of uranium ore of good quality is reported to have been found at Kawakima, in the Okuyama district.

JUGOSLAVIA

Research Reactor. Discussions are in progress between Soviet and Jugoslav representatives on the construction of the experimental nuclear reactor to be completed by late 1958. This follows on the agreement signed in Belgrade on January 28 for co-operation between the two countries on the peaceful uses of atomic energy. The reactor will be used for radio-isotope production and for gaining experience in nuclear technology and is expected to operate at a power level of up to 10 MW.

PERU

Training Institute. Following the agreement early this year between Peru and the U.S.A., the newly-constituted Atomic Energy Control Board is to set up an institute for training in nuclear physics, and is anxious to buy a research reactor as well as other nuclear equipment.

RUSSIA

A conference on high energy nuclear physics took place in Moscow from May 14-21. The conference which is sponsored by the Department of Physics and Mathematics of the Soviet Academy of Sciences includes representatives from 20 countries including Britain and the United States. Dr. T. H. R. Skyrme and Dr. Pickavance of A.E.R.E., Harwell, are representing the United Kingdom and Professor Oliphant from Australia will be present. The discussions were expected to concentrate on the design of high energy particle accelerators and on present theories concerning inter-nuclear forces. Some speculation has taken place on the role of Pontecorvo in this field.

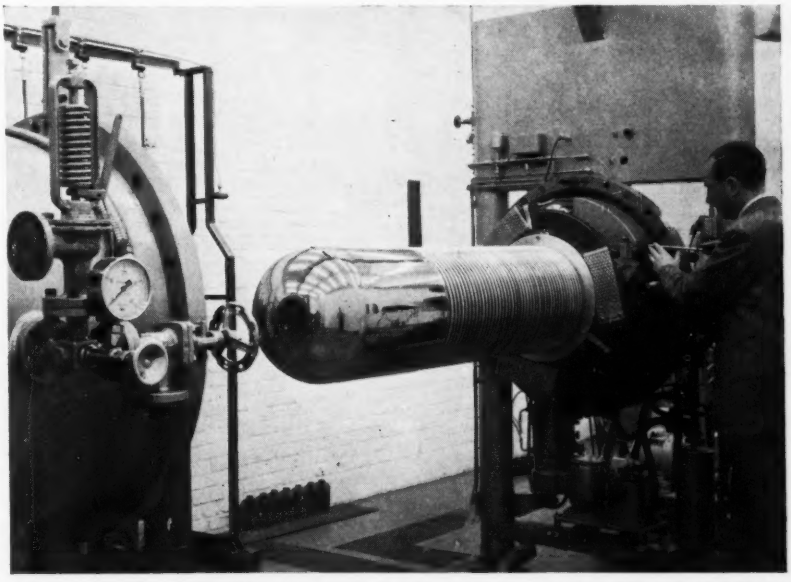
SPAIN

Swimming-pool Reactor Ordered. The General Electric Company (United States) is to supply the Junta de Energia Nuclear with a swimming-pool type research reactor. The power of the reactor is anticipated as 3 MW and will use 20% enriched uranium as fuel. Facilities include a large thermal column, experimental holes, and a pneumatic system for the handling of irradiated samples. It is to be installed near Madrid, in the Moncloa area.

SWEDEN

An international atomic energy exhibition opened in Gothenburg on May 12. The Soviet exhibit covering an area of 8,000 sq. ft. was considerably more comprehensive than their exhibit at Geneva last year. The efforts that had been taken in the display overshadowed the United States exhibit covering 4,500 sq. ft., the French and Swedish (3,000 sq. ft.) and the Danish (1,000 sq. ft.).

The first reactor school in Scandinavia has been established in Stockholm. It was intended to limit the number of students to 100, but the applications from qualified men were so numerous that 177 were accepted. Of these 15 came from A. B. Atomenergi, nine from Finland, some from Norway and Denmark and engineers from the leading Swedish engineering and shipbuilding concerns, including ASEA, De Lavals Angturbin, Henry Wallenberg and Co., Eriksbergs Mek. Verksted, Kockums, A/B Götaverken, Bofors, Nyqvist and Holm A/B, Rotor and Nyrias-Petroleum. The head of the school is Prof. Lamek Hulthen and the subjects of the lectures are theoretical physics, nuclear physics, reactor physics, reactor mathematics, reactor chemistry and experimental reactor physics.



Atelier de Constructions Electriques de Charleroi in association with High Voltage Engineering Corporation of America has installed a particle accelerator at the Institut Interuniversitaire des Sciences Nucleaires at Liege. The machine is a Van de Graaf with a continuous rated output of 2 MW and a peak output of 2¼ MW at a total ion current of 50 microamps.

USA

Industrially Owned Reactors. On May 4 the A.E.C. officially approved plans for the construction of two industrially sponsored and owned reactor power stations, one near New York City and the other near Chicago. The first of these permit Consolidated Edison of New York to build a pressurized water converter four miles north of the city on the Hudson River. The station will have a basic output of 140 MW, but an oil-fired superheater system which can increase steam temperature up to 1,000°F will give an additional generating capacity of 96 MW. Fuel for this reactor will be highly enriched uranium and the conversion of thorium to U^{223} forms an important feature of the reactor's economics. The estimated expenditure is in the region of £20 million.

The second permit has been issued to the Commonwealth Edison Co. for the construction of a dual cycle boiling water reactor with a rated capacity of 180 MW. The design and construction will be undertaken by the General Electric Co. and Bechtel Corporation has been engaged as constructional engineers. The station will be built, at a cost of about £16 million, about 50 miles south-west of Chicago at the junction of the Kankakee and Des Plaines Rivers. Both these stations are due for completion in 1960.

Aircraft Authorization. On the same day President Eisenhower gave official authorization for $70 million to be spent on test facilities for reactor-powered aircraft. This forms part of a total authorization of nearly $300 million and a supplementary appropriation of over $144 million is to be asked from Congress.

Liquid-Metal Fuel Manufacture. Babcock and Wilcox have received a contract from the A.E.C. to design and fabricate a plant for experiments using liquid metal fuels. It is probable that the initial designs will use a liquid uranium-bismuth solution and that the first experiment will be divergent some time in 1959.

Insurance Coverage. The Joint Congressional Atomic Energy Committee began hearings on a bill concerning the insurance of atomic energy projects on May 14. The main purpose of the bill is to obtain Government coverage up to $500 million against a major reactor accident. Insurance companies have already stated that they are willing to cover policies up to $65 million but that coverage considerably in excess of this is required. It is expected that settlement of the insurance problems will greatly speed American developments by giving confidence to the manufacturers undertaking new projects.

Petrol from Atomic Energy. The chairman of the Standard Oil Company of Indiana, Dr. Robert E. Wilson, when receiving the Washington award for "unusual dedication and leadership through science and engineering for the advancement of research, industry, and public affairs" suggested that the cars of the future will be run on petrol manufactured from sea-water by electrolysis using nuclear energy as the cheap source of power.

Tanker Finance Rejected. The request by President Eisenhower to the House of Representatives for $37.9 million for the building of an experimental reactor-powered tanker has been rejected by the Appropriation Committee. The President has made a number of attempts to acquire finance for the full-scale development of nuclear-propelled cargo vessels but so far has made little progress. It appears that the Appropriation Committee will first require data on the reactor-powered naval vessels now under construction before committing themselves to a merchant ship programme.

Beryllium Production. Brush Beryllium Corporation is reported to be one of the main companies interested in the A.E.C. proposals for a 250-ton production of beryllium metal over the next 5 years. The Beryllium Corporation of America is also likely to take an active part in the project whilst some 47 other companies have expressed interest in future developments.

Huge Submarine. Mr. Charles Thomas, Secretary of the Navy, in a speech to Chief Petty Officers at the Norfolk Naval Station announced that the United States was planning a huge nuclear-powered submarine which would be capable of launching a medium range ballistic missile (15,000 miles) from below the surface of the sea.

Princeton Cyclotron. The A.E.C. is to be responsible for the financing of a 3-BeV cyclotron to be built at the James Forrestal Research Centre at Princeton University. The weight of the magnet is estimated at 400 tons and the diameter of the machine is 80 ft. The accelerator is designed for research into fundamental physics problems.

M.I.T. Permission to construct a research reactor has been granted by the A.E.C. to the Massachusetts Institute of Technology. The reactor, which will operate on a power of approximately 1 MW, will use highly enriched uranium as fuel and heavy water as moderator and coolant. The purpose of the reactor is for general research and development work with particular accentuation on the biological and therapeutical aspects.

Battelle Institute developments. The first private installation of its kind for direct research on nuclear power plants has been set up by the Battelle Institute at its Columbus research centre. A critical assembly laboratory has been built for studying problems in connection with the construction of nuclear power plants and also for research on nuclear propulsion units. A hot cell laboratory was completed in September, 1955, and in addition a swimming-pool research reactor is expected to be in operation later this year.

The Institute has recently completed autoradiographic and metallographic analyses on an alloy steel containing 25% nickel 20% chromium, 3.5% copper and 2.5% molybdenum with various rare earths added to improve the hot forging characteristics. This work has been done in co-operation with Mallinckrodt Chemical Works Development Department.

Trade Notes

Esso Developments Co. Ltd. has changed its name to Esso Research Ltd. The head office remains at 33 Davies Street, London, W.1, under Mr. C. S. Windebank, managing director. The laboratories near Abingdon are in charge of Mr. K. C. Hunt.

Resin sales department of B.I.P. Chemical Ltd. is now located at Popes Lane, Oldbury, Birmingham (Telephone: Broadwell 2061).

Net profits of C. A. Parsons and Co. Ltd. and associated companies for 1955 were £1,962,613 after provision for taxation. All records in output and in turbo-generators completed and commissioned were broken.

Babcock and Wilcox Ltd., and subsidiary companies made a profit in 1955 of £4,629,498, subject to taxation but after setting aside £1,780,282 for depreciation.

Matthew Hall and Co. Ltd. has installed equipment to the value of £11 million at U.K. atomic energy establishments and has contract work for an additional £5 million, it was disclosed in the chairman's report for 1955.

The eleventh specialized course on the design, use and maintenance of electronic instruments used in nuclear physics, radiochemistry, and in work with radioisotopes will be held in the Social Club, Harwell from Monday June 11 to Friday June 15, 1956.

Winston Electronics Ltd. are to supply the Italian Government with £20,000 of electronic equipment, including decade oscillators, transistor test equipment, universal spectrum analysers and telegraph distortion measuring equipment.

Some 4,500 tons of rolled steel plate, up to 6 in. thick, are being supplied by English Steel Forge and Engineering Corporation Ltd., Sheffield, for the Calder Hall and Annan nuclear power stations. Most of it is used in the construction of the thermal shields.

The British Oxygen Co. Ltd., has opened a new works in the Milton of Craigie area of Dundee, capable of compressing 500,000 cu. ft. of oxygen per week into cylinders. The works also includes a plant for the production of dissolved acetylene.

Fuel-production plant. Mr. G. Mitchell, chairman and president of the Sylvania Electric Products Inc., has announced that a new laboratory and production plant for processing nuclear fuels will be completed by the end of 1957. The works will be entirely financed by the company and aims to provide a complete "out of pile" service for the production and reprocessing of fuel elements. A figure of many million dollars has been quoted for the capital outlay.

Milan Construction Corporation is to set up at the Brookhaven National Laboratory a laboratory for work on the liquefaction of hydrogen. The contract which has been awarded by the U.S.A.E.C. is scheduled for completion this summer.

Induction Motors Corporation, Westbury, N.Y., have established a new company in France, Société Française des Moteurs à Induction, for manufacturing f.h.p. motors, fans and blowers. Constructions Electro-mechanique Tollim, of Paris, are participating in the venture.

Vickers Limited are acquiring a 75% interest in Hoskins Engineering and Foundry Pty Ltd., of Perth, Western Australia.

Chicago Bridge and Iron Co., builders of pressure vessels and heavy-duty welded fabrications, are installing two Van de Graaff high-voltage X-ray generators at their Birmingham, Ala., works. The one-million-volt unit is fixed on the end of a rail-mounted 43-ft. boom and is intended for inspection from inside vessels. The 2 MeV machine is operated from an overhead travelling crane.

Tracer Laboratories Inc., Boston, reports that turn-over continues to increase, figures for 1955 showing a net profit of $45,000 on the turn-over of $12 million. The company is constructing a $1½ million plant near Waltham, Massachusetts, and is moving its Kelket X-ray division from Cincinatti to Boston. Dependence on A.E.C. contracts continues to decrease and represents only 15% of the company's business. Mr. M. J. Gross, at present vice-president and director of engineering of the Ritter Company, is to become vice-president of the Tracer Laboratories and general manager of the Kelket division. Mr. W. B. Barbour has been elected chairman of the board and Mr. O. Faxon becomes the new president of the company.

The Hon. Geoffrey Cunliffe has been appointed president of the Aluminium Development Association for 1956-57. **Mr. Spence Sanders** (Almin Ltd.) is the new vice-President. **Mr. J. H. Mayes** (Northern Aluminium Co. Ltd.) has been appointed chairman of the executive committee in succession to **Mr. Harold Goodwin**, who had completed two years in this office.

The Hon. Geoffrey Cunliffe is deputy-chairman and joint managing director of the British Aluminium Co. Ltd., and chairman of Aluminium Corporation Ltd., and of Aluminium Wire and Cable Co. Ltd.

Mr. Donald Watson has been appointed secretary of Atomic Energy of Canada Ltd. He will be at the company's head office in Ottawa.

Mr. P. Bernard H. Cuff has been appointed a director of Solartron Electronic Business Machines Ltd. He joined The Solartron Electronic Group Ltd. in 1955 as group controller of purchasing and stores.

Mr. Sylvan C. Coleman, a partner in the investment firm of E. F. Hutton and Co. and chairman of United Carbon Company, has been named a director of General Dynamics Corporation, N.Y.

Mr. Lewis L. Strauss, chairman of the U.S.A.E.C., received an honorary degree of doctor of laws from the Los Angeles University. In a speech afterwards he urged continued pressure on the building up of armaments until such time as disarmament becomes a practical proposition.

Dr. Ralph D. Bennett, former manager of the Knowles Atomic Power Laboratory technical department, will head the General Electric Vallecitos Atomic Laboratory which will be in operation at Pleasanton, California, in 1957.

Mr. H. A. Masters, formerly assistant engineer-in-charge at the B.B.C.'s Daventry transmitting station, has been appointed engineer-in-charge there in succession to **Mr. F. N. Calver**, M.B.E., who has retired.

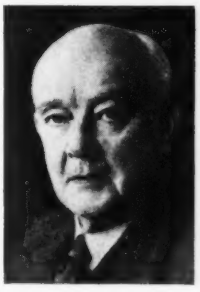
Sir Edwin Plowden in his tour of the United States atomic energy installations visited the Shippingport generating station on May 7.

Dr. Joseph Austen Bancroft, B.A., A.M., Ph.D., D.Sc., has been awarded the Gold Medal of the Institution of Mining and Metallurgy in recognition of his services to the mineral industry in South Africa and in the advancement of the science and practice of economic geology.

Personal

Sir Ronald Matthews.

Mr. G. C. R. Eley.



Major W. R. Brown.

Mr. T. K. Hargreaves.

Sir Ronald W. Matthews, D.L., M.Inst.T., has relinquished the chairmanship of the Brush Group Ltd. which he has held for 18 years; he will remain on the board, however. **Mr. G. C. R. Eley**, C.B.E., deputy chairman, succeeds Sir Ronald as chairman.

Viscount Chandos, D.S.O., M.C., was re-elected president of the British Electrical Development Association for the year 1956/57. **Mr. H. J. Randall**, C.B.E., chairman, London Electricity Board, **Mr. S. F. Steward**, C.B.E., ex-chairman, South-Western Electricity Board, and **Mr. E. R. Wilkinson**, C.M.G., M.I.E.E., former chief commercial officer, Central Electricity Authority (all former chairmen of E.D.A. Council) and **Mr. E. H. Mullens**, B.Sc., M.I.E.E., ex-chairman, North-Eastern Electricity Board, were elected as vice-presidents of the Association.

At the first meeting of the new council, **Mr. D. Bellamy**, O.B.E., chairman of the Yorkshire Electricity Board, was elected chairman, and **Mr. W. S. Lewis**, C.B.E., chairman, Midlands Electricity Board, was appointed vice-chairman for the current year.

Major W. R. Brown, D.S.O., has been elected vice-chairman of the Power-Gas Corporation Ltd., Stockton-on-Tees. **Mr. T. K. Hargreaves**, D.S.O., M.A., A.M.I.Mech.E., has been appointed a director.

Mr. I. C. Raymond Atkin, vice-president, J. P. Morgan and Co. Inc.; **Mr. Gordon R. Ball**, president, Bank of Montreal; **Mr. James S. Duncan**, C.M.G., chairman and president, Massey-Harris-Ferguson Ltd.; **Mr. William J. Hutchinson**, consultant and former treasurer of the company; **The Rt. Hon. Lord McGowan**, K.B.E., member of the company's advisory committee and director of the London and Lancashire Insurance Co. Ltd.; **Mr. Donald H. McLaughlin**, president, Homestake Mining Co.; **Dr. Paul D. Merica**, consultant and former president of the company; **Sir Otto E. Niemeyer**, G.B.E., K.C.B., director of financial enterprises; **Mr. Grant B. Shipley**, director and consultant, Elliott Co.; **Mr. R. Ewart Stavert**, president, the Consolidated Mining and Smelting Co. of Canada Ltd.; **Mr. J. C. Traphagen**, chairman, The Bank of New York; and **Mr. Henry S. Wingate**, president of the company, were all re-elected directors of the International Nickel Co. of Canada Ltd., at the A.G.M. on April 25.

Dr. John Conby, of Ottawa, director of the Federal Mines Department, has been awarded the Selwin G. Blaylock medal in recognition of his contribution "to metallurgical advances and the extraction and concentration of fissionable materials and in the development of controlled atomic energy in Canada." The award was made at the annual dinner of the Canadian Institute of Mining and Metallurgy.

Mr. C. G. Hancock, A.M.I.E.E., assistant labour relations officer at the Central Electricity Authority's Headquarters, has been appointed a deputy labour relations officer at headquarters in succession to **Mr. G. W. Essex**, who has retired.

Dr. William I. Thompson has been appointed chief of process engineering in the research laboratory of General Dynamics Corporation General Atomic Division in San Diego.

Mr. F. Gordon Kay, A.M.I.Mech.E., sales manager of Acheson Colloids Ltd., is on an extensive tour of South America. He is visiting Brazil, Uruguay, Argentina, Paraguay, Chile, Peru, Colombia and Venezuela, covering over 22,000 miles by air.

OBITUARY

It is with deep regret that we record the death on April 26 of **Mr. T. L. Horabin**, chairman of K.D.G. Instruments Ltd. **Mr. R. B. Ogden**, F.C.A., a member of the board, has been appointed the new chairman.

It is with deep regret that we have to record the sudden death on May 5 of **Dr. S. Whitehead**, director of the British Electrical and Allied Industries Research Association.

Technical Papers and Publications

B.N.E.C.

Paper presented at the Royal Institution, Albemarle Street, London, W.1, on May 3 sponsored by the Institution of Chemical Engineers.

Some Problems in the Maintenance of Nuclear Reactors *by H. G. Davey, O.B.E., M.Sc. (Works General Manager, U.K.A.E.A., Windscale).*

When the Windscale reactors were being designed it was assumed that after they went on to power those parts which had been subjected to radiation could not be maintained. Therefore, a fundamental concept for design was, as far as possible, to make the reactor itself static and to keep moving parts outside the biological shield. For example, as the piles were air-cooled the air had to be either pulled or pushed through the reactor. Pushing was chosen because this meant that the large fans would remain inactive and not become contaminated and, therefore, could be given normal maintenance.

Over a period of time those items contained within the reactor proper and which had been subjected to the influence and effect of flux, temperature, and air flow developed faults and, therefore, unusual and to some extent unexpected maintenance work has had to be done under reactor conditions. It will be appreciated that each problem, as it presented itself, was novel and therefore special techniques had to be evolved to carry out what were in themselves simple mechanical operations but which were made difficult by the unusual circumstances and the hazards.

The paper gives examples of the work which has been done, the techniques which have been evolved for doing the work and the precautions which have been taken to ensure that the personnel engaged on this work were not contaminated and did not receive radiation doses in excess of the limits laid down by the Medical Research Council.

After five years' operating experience the author is satisfied that given certain facilities and following the techniques which have now been evolved, a reactor can be a maintainable unit. This will have a fundamental effect on the design of future reactors.

Situated outside the biological shield, and therefore available for normal scheduled maintenance, are eight large fans (each driven by a 2,300 h.p. motor and energized from an 11 kV supply), booster and shut-down fans, frequency changers and exhausters, overhead cranes, driving mechanisms for control and shut-off rods and burst cartridge detection gear, haulage gear operating in the water duct, and a variety of instruments and controllers. The charge hoist is situated between the two portions of a split biological shield, but even this hoist is accessible for maintenance when the reactor is shut-down.

It will be seen that the outstanding exception to the rule that moving equipment should be outside the biological shield is the burst cartridge detection gear. This is a substantial stainless steel structure which moves vertically up and down the back face of the graphite lattice inside the biological shield.

During the past 5½ years these reactors have given remarkably little trouble and, in fact, have been in production for 93% of the possible time. (The lost 7% includes shut-downs for discharging and charging fuel elements.) It is necessary to emphasize this because, although from time to time problems have arisen which constituted a challenge to ingenuity, they have not caused prolonged shut-downs.

Maintenance work can be divided into two broad categories: remote work and direct work with temporary shielding.

Remote Work. The general principle is that all personnel must remain outside the biological shield and techniques, tools, and equipment have been devised for carrying out operations remotely. It will be appreciated that no serious radiation problem need arise, but careful planning and supervision are necessary to avoid gamma beams from open holes and for handling irradiated tools and equipment when they are withdrawn through the shield.

After the reactors had been in operation for two years, cartridges were discovered in the air outlet ducts and in the trucks located in the water duct. Investigations suggested that failure of the boat-to-boat linkage had caused cartridges to be ejected from the channels one at a time.

Fitted on the stringers on the back face of the graphite lattice were clips which had been given the popular name of curtain rails. Five-foot lengths of aluminium tube were threaded on, and fixed to, a ¼ in. steel rope which was about 60 ft. long. The joints between the tube and the wire were faired and the leading length had a spear point. Such an articulated rod was fed through each hollow plug in 4-in. holes in the roof above the vertical rows of channels, the plug helping to guide the leading spear into the first curtain rail. Correct positioning of the rod was checked by a periscope and an introscope through 10-in. inspection holes in the roof, but visibility was severely restricted by the burst cartridge detection gear.

The first objective, the retaining of the charge, was achieved, but such an arrangement presented its own problems. Every time it was necessary to discharge cartridges from the reactor, the corresponding articulated rods had to be withdrawn and subsequently replaced. Occasionally trouble was experienced due to deformation of individual lengths of aluminium tube and damage resulting from mechanical wear and tear. Special tools for pulling, pushing, and twisting the articulated rods had to be developed and these tools had to be remotely operated from the reactor roof at distances up to 60 ft.

By introducing a television camera and introscopes through inspection holes in the roof and charging holes in the charge face, the back and front baffle plates of each reactor were inspected. Front face plates showed no deterioration whatsoever, but on the back faces some bolts were found to be missing and plates were loose. Evidently vibration was the cause of the trouble and the position worsened rapidly.

The first serious difficulty was experienced on Reactor No. 2. The driving motor of the burst cartridge detection gear came out on overload and, after shutting down the reactor, an inspection was carried out. One scanner arm was seen to be fouled by the top edge of a plate which had become loose and was bent away from the graphite face. It will be realized that, by working remotely through the 4-in. holes, only limited force could be applied to the plate and attempts at straightening were unsuccessful. It was then decided to try to cut the plate with a welding torch. An oxy-acetylene torch was lowered through a 4-in. hole and observed and directed by means of an introscope inserted through an adjacent 4-in. hole. The plate was roughly cut for the greater part of its vertical length and, thus weakened, was returned to position without great difficulty and held there with rods.

This, and similar work involving the use of a welding torch, inspired a much more ambitious programme. Could reasonable welding precision be attained in such circumstances? Would spot welding of bolt heads and welding of bolt plates to one another and to curtain rails be possible?

A full-scale mock-up was constructed which simulated exactly the conditions under which the repairs would be carried out, and enabled practice to take place under inactive conditions. Over a period of a few weeks, satisfactory tools and techniques were evolved and welders adapted themselves to the strange working conditions.

To date, 121 bolts have been spot welded and 180 strengthening welds have been made. The baffle plate assemblies as a whole are now adequately mechanically strengthened and development work is proceeding to undertake welding and the replacement of a few missing plates from even more remote positions.

Shielded Work. During an inspection on Reactor No. 2 in May, 1955, a scanner guide shoe bracket with four holding bolts sheared and, still in position, was found in a skip. The shoe itself had been sheared off where the 2-in. diameter pin entered the bracket and the shoe was missing. A radiation survey was carried out and the general level near the floor of the water duct was 80 r per 8 hours. The matter was serious because of the function of the burst cartridge detection gear. This gear, which consists essentially of eight scanners, is vital to the reactor operation. It gives an early indication of a cartridge failure and thus enables the faulty cartridge to be discharged before the burst can develop to a point where radioactive contamination of the back of the reactor might occur. Remedial action was, therefore, imperative.

Investigations into plate sizes and handling problems showed that it would be possible to suspend a plate 2 in. thick by approximately 16 ft. x 5 ft. wide from the

outer roof inspection hole using the reactor crane already installed. A 2-in. thick end shield could also be suspended from the inner west inspection hole and dropped into position so that the lower end rested on the floor of the duct whilst the upper end leant against the roof shield thus forming, with the sides of the duct and the end wall of the discharge area, a box inside which work could be done. The roof shield could be propped from below, leaving the crane free. As the minimum height of the roof shield above the floor level would be about 16 ft., some additional shielding along the front and rear walls of the water duct and the end wall of the discharge area would be necessary to cover the lower additional thermal shield plates.

In the early stages of planning, it was realized that good communications would be essential since in order to do the job in the duct equipment would be used on the reactor roof in the West Rear Court and at the winch end of the water duct. Three types of communication were set up:

(a) Frogmen's intercommunication sets positioned on the reactor roof, in the water duct and at the winch house. These proved very satisfactory and enabled the supervisor in charge in the water duct to call for effort from, and to give instructions to, the other stations.

(b) Standard intercommunication sets positioned on the reactor roof in the water duct and West Rear Court. These were used mainly for directing the movement of men and materials in and out of the water duct.

(c) Field telephones were set up as standby in case the other methods failed to operate.

The shielding and the rolled guide bracket were fabricated in the workshops and concurrently all other necessary preparatory work was done.

A briefing lecture was given to all who were to take part in the work, and during this lecture every aspect of the job was discussed in detail; the radiation hazard was stated clearly and the plan was described which had been evolved to ensure that no man would receive an overdose.

Remote surveys had been made of the radiation levels at the back end of each reactor. Measurements had been made immediately after a reactor was shut-down and at various time intervals up to five days after shut-down. Measurements had been carried out with unshielded instruments and with instruments shielded by ½ in., 1 in., 2 in. and 4 in. M.S. plates. Thus data had been obtained on gamma dose rates at representative points and the attentuation to be expected by using M.S. shields of various thicknesses had been determined.

There is an initial rapid decay of the reactor activity after shut-down. This continues for about 24 hours then the rate of decay becomes very slow. Two hours after shut-down the radiation level opposite the centre of the graphite core is about 10,000 r/8 hours (about 200,000 m.p.ls.) and after 1-2 days 2,000 r/8 hours.

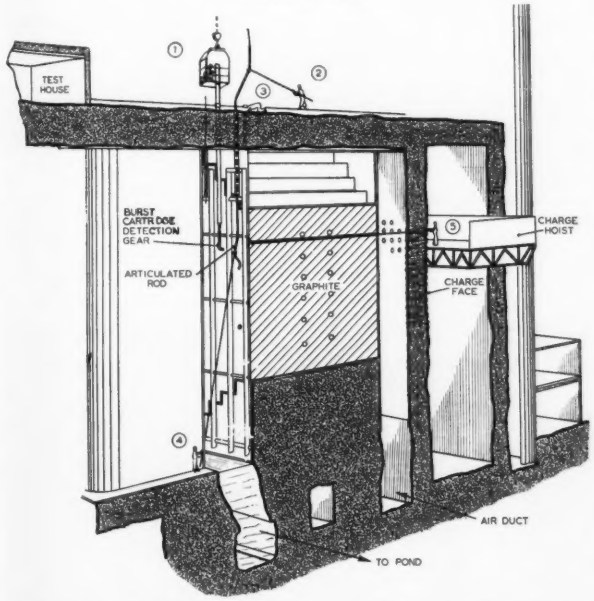
Below the graphite core the radiation field drops rapidly. At the position of the shoe brackets the radiation level 48 hours after shut-down is 500-600 r per 8 hours (about 10,000 m.p.ls.). The field gradient in this region is extremely steep and a movement up or down of about 1 ft. produces a change of 100 r per 8 hours in the radiation level. At 15 ft. above the floor of the water duct, the radiation level is 200 r per 8 hours and the gradient 30 r per 8 hours per foot. The general radiation level at head height above the floor of the water duct is 60-80 r per 8 hours, which represents the limit for short time workings as, in field levels greater than this, adequate control of personnel is virtually impossible.

It has been found experimentally that 2 in. of mild steel allowed about 15% transmission of the radiation and, therefore, by mounting a top shield 2-in. thick at the proposed height, it was estimated that immediately under this shield the radiation level would be 9-12 r per 8 hours which would give a man a working time of about 25 minutes, and this was the figure on which the work was planned.

The method adopted was essentially an exercise in team work and planning and every man worked in the company of his fellows and under constant supervision.

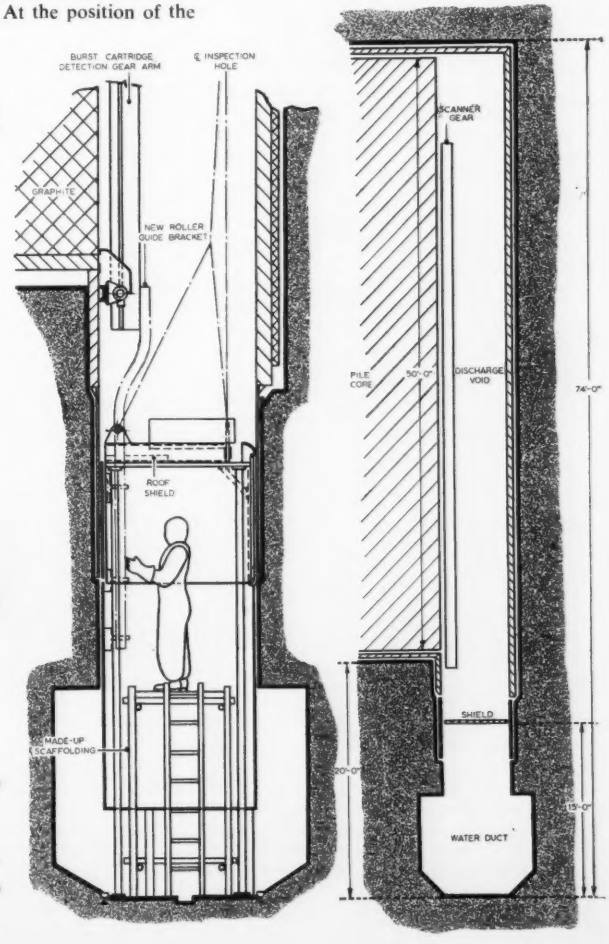
It is thus important to provide accurate, detailed, record drawings of reactor construction, even if, at the time of construction, it is considered that some regions, ultimately, will be inaccessible.

Right—General view of the discharge void over the water duct and a sketch of shielding erected for repair on the burst cartridge detection gear.



1. OPERATOR CONTROLLING OPERATIONS FROM PERISCOPE SUSPENDED FROM CRANE.
2. REMOTE HANDLING OF ARTICULATED ROD.
3. VIEWING THE JOB BY TELESCOPE THROUGH A PLUG HOLE.
4. WORKING FROM THE AIR DUCT—TIME VERY LIMITED.
5. MAN ON CHARGE HOIST OPERATING GEAR THROUGH EMPTY CHANNEL.

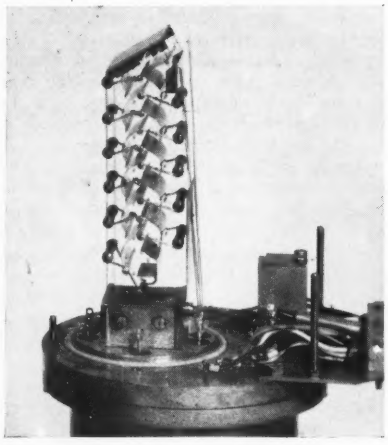
Above—Diagrammatic view of the type of operation undertaken to locate articulated rods in the curtain rails.



Physical Society Exhibition

THE 40th Physical Society Exhibition, held in the Royal Horticultural Society Halls, London, from May 14-17, contained more prototype and research equipment than has been the general tendency over the past few years.

Transistorized circuits formed one of the main subjects of the Exhibition and included prototype and production equipment for such diverse applications as a portable oscilloscope shown by Mullard Ltd., operated from a 12-volt accumulator, a time base calibrator for the range 10-2,000 μ sec. by British Thomson-Houston Co. Ltd., a variety of potted circuits by Fortiphone Ltd., a force and displacement indicator forming an electric micrometer with a span of 0.010 in. and stability of 0.0001 in./hr. developed by Shell Research Ltd., and a radiation monitor by Panax Ltd. who also have available a range of aluminium absorbers from 1.6-1,000 mgm/cm^2.



Demountable electron multiplier assembly by Metropolitan-Vickers for use with the mass spectrometer type MS2. It comprises eleven stages of the Allen type with provision for end-on collection.

Ceramics are playing an increasing role in high insulation applications and were featured by the Research Laboratory of the General Electric Co. Ltd. Ceramic envelope valves exhibited by Ferranti Ltd. are suitable for operation over the range 200-2,000 Mc/s. A vibrating reed unit manufactured by Electronic Instruments Ltd. uses a ceramic seal for the input electrode the impedance to case being quoted as 10^{16} ohms. The company is collaborating with Ericsson Telephones Ltd. in the production of the electrometer type 1086 developed in conjunction with A.E.R.E., Harwell.

Automatic or remote reading chemical apparatus was in greater evidence, typified by the remotely controlled pH measuring and recording instrument featured by W. G. Pye and Co. Ltd.

A number of thickness gauges and industrial isotope application equipment were featured by Ekco Electronics Ltd., Baldwin Instruments and Isotope Developments Ltd. The first two companies mentioned have made a feature of automatic standardization and I.D.L. has a gamma ray thickness detector which uses a scintillation counter as a D.C. source of current, which is in turn backed off by an ionization chamber.

A wide range of laboratory equipment for nuclear physics experiments is now available to prospective purchasers. Amongst a number of new instruments on show for the first time is the Panax automatic scaling unit D4122, designed to contain in one unit all the basic functions such as scaler, ratemeter, timer and amplifier, etc. The Dynatron dekatron scaler type 1287A has been made in portable form specifically for field work; a fast amplifier type 1413A is a new version of the old 1049. A new range of counting subsidiary units is now available from Ericcson Telephones Ltd. who were also showing a new scaler, type 1357, and reactor instrumentation for the swimming pool reactor LIDO. The equipment when finalized will be installed in duplicate form. Specifications are not yet available for the Philips Electrical Ltd. fast scaler 1070B but provisional estimates give a resolution time of 0.25 microsec.

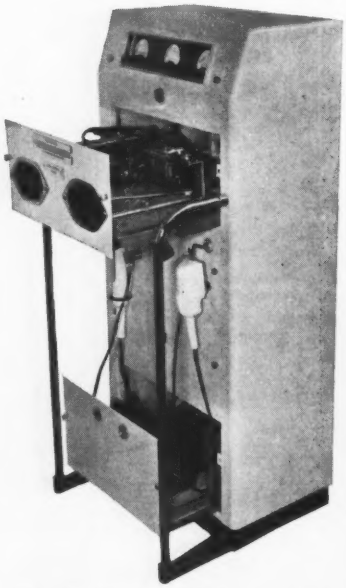
The two current types of multi-channel kicksorter could be compared at Sunvic Ltd., showing the Scarriott Hutchinson type, and Philips showing the Wilkinson type. Sunvic are developing a system for converting the binary system into a dekatron presentation. In the meantime the 1438B is now commercially available. Also on the Philips stand is the modified contamination monitor for hands and clothing, type 1404A, which is a simplified version of the hand and foot monitor and has been designed with Calder Hall specifically in mind. A number of these instruments have already been delivered.

A comprehensive range of pulse generators is now available for test purposes. Specifications cover a wide range of pulse length, width, frequency and shape. Nine companies in all were exhibiting new or improved models.

Two recent advances in electron multiplier production have been made, 20th Century Electronics exhibiting for the first time their photo-multipliers of the Venetian blind type which will be put into production in the near future. Metropolitan-Vickers Ltd. were exhibiting an electrode assembly suitable for mass spectrometer detection work.

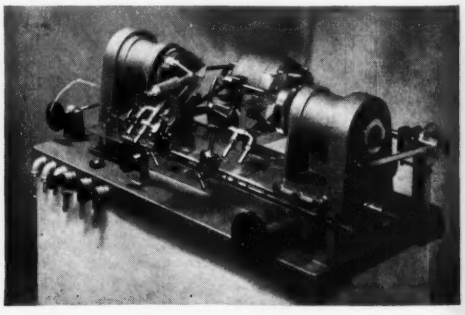
Recent improvements in the Edwards glass working lathe have produced a very useful machine. Also exhibited was a VS5 vacuum switch which can be set to operate at 10^{-3} to 10^{-5} mm. Hg.

A prototype system for the easy changing of radioactive scintillation liquids was shown by the Middlesex Hospital for C_{14} and H_3 determinations.



The simplified radioactive contamination monitor for hands and clothing type 1404 A manufactured by Philips for installation at Calder Hall. The instrument has been constructed to facilitate cleaning.

Transistorized portable battery monitor type TR 56—prototype of Panax new detection monitor with two logarithmic ranges. Instrument incorporates a new Mullard gamma counter MX 120/01.

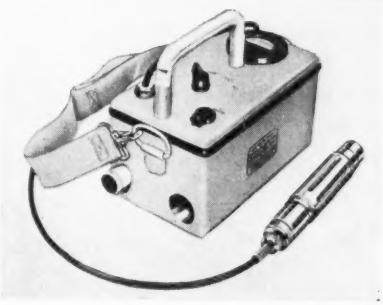


Edwards glass-working machine, model G3 of particular value in the laboratory where semi-skilled effort only is available. Maximum jaw opening 60 mm., maximum work dia. 222 mm. and up to 32 mm. dia. tubing can be taken through chucks.

Processes and Equipment

(Right). An operator using a remote control apparatus in a pharmaceutical dispensary for gamma-emitting isotopes. She is screened by a lead wall and observes the operation through a 6-in. lead glass window together with a mirror suspended above the plant.

(Below). The Atomlab model DG-700 beta/gamma discriminating radiological survey meter designed to U.S. Federal Civil Defence Administration specifications.



Static Elimination

Static charges are a frequent source of error in high-precision weighing. Chemical balances of the free-swinging type, modern aperiodic instruments and microbalances are all affected. Certain kinds of flasks, dishes and vessels used are also prone to acquiring static charges.

Stanton Instruments Ltd., 119 Oxford Street, London, W.1, now offer a radioactive source for static elimination in all types of precision balance. The isotope used emits only β particles, a comparatively large area source of low surface activity being chosen to give maximum efficiency, whilst allowing almost all radiation to be retained within the balance case.

The device is supplied in a mount which incorporates automatic radiation protection for the operator when loading the balance.

Insulation Blocks

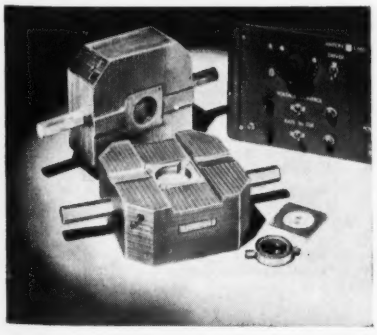
A new slab insulating material, known as Insulex, combining the best features of both moler and fibrous types of heat insulators has been developed by Moler Products Ltd., Hyther Works, Colchester, Essex. The material comprises diatomaceous earth, asbestos fibre and exfoliated vermiculate, and the slabs are particularly suitable for plated wall construction. The temperature limit is 1,700°F at the hot face, the compressive strength being 182 lb. per sq. in. to $\frac{1}{8}$ in. before heating, and 112 lb. after heating to 1,600°F for 24 hours. The transverse strength is 36 lb. per sq. in. Linear and volume shrinkage after soaking is 2.4% and 7.1% respectively at 1,600°F.

Sample Changer

A sensitive shielded manual sample changer designed to provide 2-in. lead and $\frac{3}{16}$-in. aluminium in all directions is now available from Anton Electronic Laboratories Inc., 1226 Flushing Avenue, Brooklyn 37, N.Y. Background is said to be reduced by a factor of from 2 to 4.

Counting geometrics with the model 6001 of nearly 100% are provided by the use of special counter tubes. These are mounted facing each other, with windows 0.312 in. apart. Low background and high sensitivity make possible the quick and accurate measurement of weak sources. Counting can be carried out with one tube, the other being connected in anti-coincidence or entirely removed.

The tubes, types 1001H and 1001T, are self-quenching high-sensitivity alpha and beta units with mica windows, which are thinner than in previous models. The flat pancake shape of the counters provides a large diameter window without increasing the volume and accompanying high background count.



Anton model 6001 shielded sample chargers with a flat pancake-type counter tube in the right foreground.

Survey Meter

A beta/gamma discriminating radiological survey meter designed to Federal Civil Defence Administration specifications has been announced by the Atomic Center Inc., 489 Fifth Avenue, New York, 17, N.Y.

The model DG-700 employs a Geiger type detector, a pulse shaping network, and a count-rate circuit with meter and earphone indication. Sensitivity ranges are 0-50, 0-5 and 0-0.5 mr/hr., read on a 50μA, 2$\frac{1}{2}$-in. meter, with an accuracy of $\pm 10\%$ of full scale. The instrument is sensitive to beta radiation having energies above 175 keV, and is provided with a mounted 0.25-microcurie Sr_{90} calibrating source.

The instrument has an electronic high voltage supply operating off low-voltage batteries with a life of over 130 hours per 8-hour day operation. It measures 4$\frac{3}{4}$ in. x 4$\frac{7}{8}$ in. x 8$\frac{7}{8}$ in. and weighs 6 lb.

Lead Glass Windows

Chance lead glass blocks are available in the standard size of 6$\frac{1}{4}$ in. x 6$\frac{1}{4}$ in. x 4$\frac{1}{2}$ in. (approx. 16 cm. x 16 cm. x 11 cm.), which can be ground and polished to 6 in. x 6 in. x 4 in. Although larger sizes are manufactured, the usual maximum thickness is 4$\frac{1}{2}$ in.

The heavy lead glass used for the blocks is stirred whilst molten; that is, the same process is used as in the manufacture of optical glass where homogeneity is essential. The blocks, therefore, are substantially free from internal striae, and objects can be seen through them without distortion. To prevent darkening caused by high-energy radiation cerium oxide is added.

The makers are Chance Brothers Ltd., Smethwick, Birmingham.

Priming Paint

Pitan etch primer paint is based on a special vinyl resin and contains rust inhibitors. It forms a firm bond to metal surfaces providing a strong key for subsequent coatings. It consists of a base and an activator which must be mixed together, and used within 8 hours of mixing.

It is suitable for application on iron, steel, aluminium, tinplate, zinc, and galvanized iron, with subsequent coatings of epikote-based paints, chlorinated rubber paints, oil paints, and enamels.

It is made by Allweather Paints Ltd., 36 Great Queen Street, London, W.C.2.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 745,460. Electromagnetic liquid metal pumping systems. O. O. Pulley. To: U.K. Atomic Energy Authority.

This specification refers to pumps in which a current is caused to flow through a liquid conductor in a duct perpendicular to a magnetic field. In such a system, the difficulty is to provide a low voltage, high current source. In this patent primary and secondary liquid metal ducts are arranged in an air gap in a magnetic circuit as shown in Fig. 1, in which (1) is the primary duct and (6) the secondary duct, both lying in the gap between the pole pieces (2) and (3). If liquid metal

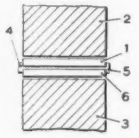


Fig. 1. B.P. 745,460.

is forced through the primary duct, an E.M.F. will be generated across the duct, and if electrical connections (4) and (5) are made between the two ducts, then a current will flow in opposite directions in the ducts. The interaction of this current with the magnetic field will produce a drag on the liquid conductor and power will be required to force the fluid through the primary duct. A similar interaction will create a pumping force in the secondary duct tending to drive the secondary fluid in the same direction as the primary flow in duct (1). The system is applicable in arrangements wherein two separate fluid circuits are used. The specification gives equations for the pressure in the ducts and the efficiency and also various arrangements of ducts and connections.

B.P. 745,807. Electromagnetic pumps. To: Allmanna Svenska Elektriska A.B. (Sweden).

To raise the efficiency of this type of pump, which up to now has not been higher than 37%, an equalization of the pressure and speed throughout the cross-section of the flat rectangular tube carrying the liquid metal through the magnetic field is desirable. This is achieved by the provision of metal rods of high electric conductivity arranged at the short sides of the tube. Fig. 2 illustrates the eddy current distribution obtained with the new pump through the rods (1) along the sides of the outer channels of the tube. The component Sz is practically the same in all channels whilst the component Sx in the direction of flow is practically suppressed.

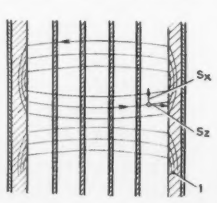


Fig. 2. B.P.745,807.

B.P. 746,456. Apparatus for pumping liquid metal. J. M. Findlay (U.S.A.).

The four known types of electromagnetic pump, the direct current (Faraday), the alternating current conduction, the alternating polyphase conduction and the electromagnet centrifugal type have certain disadvantages. A laboratory type pump designed to overcome some of these disadvantages and to be efficient over a wide range of temperatures, pressures and flow rates is shown in perspective in Fig. 3. Liquid metal enters through (4) the arcuate path of the conduit (1) while the permanent magnets (2) and (3) on shaft (6) are rotated in the direction of the arrow, by an electric motor. The movement of the poles of the magnets along the conduit creates forces which act on the liquid metal in the conduit forcing it through the exit (5). The principle of the creation of the forces is explained in the specification with reference to an eddy current brake. Any desired number of magnetic poles may be used. The permanent magnets may be replaced by direct-current electromagnets. A pump for delivering 3,000 g.p.m. at 30 p.s.i. is also described and illustrated in the specification.

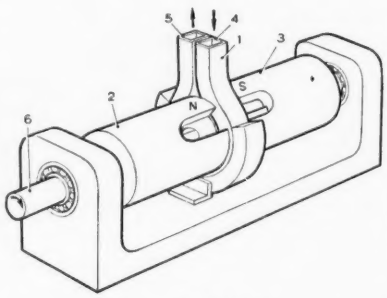


Fig. 3. B.P. 746,456.

B.P. 747,015. Electrical radiation detecting apparatus. W. F. Cotty.

For detecting alpha, beta, gamma and X-rays, and cathode rays, a diamond is used in a pinpoint detector in a portable apparatus. The diamond receives an electrode wire in a drilled hole on top of a flexible coaxial cable. The other electrode is constituted by a metal screen around the diamond. No bulky clamping device is required. Probe, pre-amplifier and main amplifier, together with the indicating instruments (counting rate meter, oscilloscope, loudspeaker) are all connected by flexible cables and push-on plugs.

B.P. 747,474. Polymeric substances. A. Charlesby, M. Ross. To: U.K. Atomic Energy Authority.

The physical properties of polymeric substances having a chain structure (carbon atoms; carbon atoms with hydrogen atoms attached thereto) can be improved by subjecting them to ionizing radiation (B.P. 729,709). Articles of small size may receive a dose of 10^{17} thermal neutrons per sq. cm. but the irradiation of large articles in present thermal nuclear reactors is not practicable as it is not possible to fabricate large articles by known welding methods or make use of adhesion by cements. Joints can be made, however, if between the surfaces to be joined a polymeric substance is interposed of the same composition but having received a smaller amount of ionizing radiation and the weld is then made under pressure at a raised temperature. The examples given in the specification refer to polythene but other substances (polystyrene, polyvinyl chloride, polyvinyl acetate, polyvinyl alcohol) are also mentioned.

B.P. 747,478. Polymeric substances. A. Charlesby. To U.K. Atomic Energy Authority.

If polymeric substances of very high average molecular weight exceeding 25,000 are subjected to a relatively short irradiation from high energy sources the products are superior to those of lower average molecular weight given longer irradiation times. In particular the tensile strength at temperatures above 120°C is increased. A rod of polythene of average molecular weight about 40,000 was enclosed in a close fitting aluminium can and subjected to irradiation in a reactor. The thermal neutron flux was about 10^{12}, the temperature 80°C, the irradiation time two hours. The resulting substance was insoluble in usual organic solvents and had a higher tensile strength above 120°C than irradiated polythene of the lower molecular weight (20,000 to 25,000).

Catalogues

Anton Notes.—A four-page catalogue of radioactivity-measuring instruments, counter tubes and voltage regulator tubes issued by Anton Electronics Laboratories Inc., 1226 Flushing Avenue, Brooklyn 37, N.Y.

Marconi Instrumentation.—The March issue of this quarterly technical instrumentation bulletin contains articles on the new Marconi counter-type frequency meter, fine tuning controls on signal generators, and the type TF 455E wave analyser. Marconi Instruments Ltd., St. Albans, Herts.

Evershed News.—Articles on instruments for plant maintenance and supervision, and on automatic control of soaking pits are contained in the April issue of this bulletin issued by Evershed and Vignoles Ltd., Chiswick, London, W.4.

Plessifex.—A well-illustrated catalogue of the sizes and other leading data of the new Plessiflex seamless, flexible metal hose for the conveyance of liquids or gases at high pressures. Power Auxiliaries Ltd., Kembrey Street, Swindon, Wilts.

Titanium No. 1.—Information sheet detailing recommendations for the production of sound ductile welds on titanium by the Argonarc process. Issued by British Oxygen Gases Ltd., North Circular Road, Cricklewood, London, N.W.2.

Tracerlog.—The March issue contains information on the Tracerlab well-type gamma tube, the P-20B scintillation detector, the Four Pi counter and the PIP-13 uranium-thorium ore analyser. Tracerlab Inc., 130 High Street, Boston, Mass.

Cathode-ray tube data sheet.—A list of the principal physical and electrical characteristics and applications of 74 Du Mont standard cathode-ray tubes. Obtainable from the industrial tube sales department of Allen B. Du Mont Laboratories Inc., 750 Bloomfield Avenue, Clifton, New Jersey, U.S.A.

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